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THE EFFECT OF SYSTEM DEPOLARIZATION

ON MEASUREMENT QUALITY

APPROVED:

Andrew J. Blanchard
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THE EFFECT OF SYSTEM DEPOLARIZATION ON MEASUREMENT QUALITY

by

ROBERT JAY NELSON

Presented to the Faculty of the Graduate School of
The University of Texas at Arlington in Partial Fulfillment
of the Requirements
for the Degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

THE UNIVERSITY OF TEXAS AT ARLINGTON

May 1986

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April 1, 1986

ABSTRACT

THE EFFECT OF SYSTEM DEPOLARIZATION
ON MEASUREMENT QUALITY

Robert Jay Nelson, M.S.
The University of Texas at Arlington, 1986

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Radar systems are susceptible to depolarization effects caused by the system and the environment. System effects include depolarization caused by antennas and measurement configurations. Antenna effects arise from the assumption that the cross polarization isolation response is infinite across the beamwidth of the antenna. In fact, the isolation response can be as high as -20 dB at boresight to 0 dB 2-3 degrees off-axis. Depolarization due to measurement configurations comes from the translation necessary to match antenna coordinate system to the clutter coordinate frame. For large beamwidths at small angles of incidence this translation can cause significant depolarization. These phenomena have been investigated separately in the monostatic case.

This research extends previous work done in the monostatic case to the bistatic case. A computer simulation was developed which models a bistatic clutter environment. The simulation models depolarization sources caused by system and surface effects. A linearly polarized wave is sent through a transmitting antenna. The coordinate frame of the

transmitted wave is matched to the clutter frame. The clutter scatters a portion of the wave toward the receiver. The coordinate frames are translated and the wave proceeds through the receiving antenna. The result is a "depolarization figure of merit" attributable to the system effects investigated. Baseline runs were done to establish the effect of the individual depolarization source on the degradation of system performance. Significant depolarization was found to occur off-axis due to the individual contributions of both translation and antenna effects. When combined, these effects can create a large signal contribution located off-axis due solely to system induced depolarization. This additional noise will serve to hide any target located in the boresight of the antenna. The conclusion reached from this analysis is that the inclusion of system induced depolarization effects in the modeling of a radar performance is paramount in evaluating the system capability.

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CHAPTER ONE

INTRODUCTION

The measurement of cross-polarized scattering information is becoming more and more important in today's modern radar cross section measurement equipment. Knowledge of the scattering processes, measurement geometry, and system-induced depolarization effects is important in order to properly assess the quality of the measurements actually made.

This thesis explores two different system induced depolarization effects to assess their influence on the quality of scattering measurements made in a bistatic environment. A bistatic environment exists when the transmitting and receiving antennas are in two different locations. When the transmitting and receiving antennas are in the same location, a monostatic environment exists. The two system induced depolarization effects studied are translation depolarization and antenna depolarization. Translation depolarization occurs when the coordinate frame of the antenna (transmitting or receiving) is different than the coordinate frame of the scattering surface. Antenna depolarization occurs from the imperfect isolation of the like- and cross-polarized channels of the antenna. The combined effect of these two depolarization phenomena can lead to errors greater than the expected cross-polarized scattering coefficients created by a scattering surface. Previous studies of these effects have been done in the monostatic case. This research extends the previous work to the bistatic case.

This paper is divided into four separate sections. First, chapter two provides the background of research done in the past to study the scattering process and system depolarization effects. Chapter three provides the theoretical basis for extending known

system effects (translation depolarization, antenna depolarization, and scattering depolarization) to a bistatic geometry. Chapter four describes the computer model designed to simulate the bistatic measurement of like- and cross-polarization scattering coefficients from a random surface. Chapter five analyzes the results produced by the computer model to demonstrate that system induced depolarization effects do occur in the bistatic measurement environment. Finally, chapter six presents the conclusions reached from the analysis of simulation results and provides recommendations for decreasing, or even eliminating, system induced depolarization effects from the measurement of surface scattering in the bistatic environment.

CHAPTER TWO

BACKGROUND

The complete use of the polarization properties of scattering bodies is important in order to fully retrieve all information about a radar target. The accurate measurement of all polarization characteristics of a target requires specific radar system performance criteria in order to assure correct data collection. This chapter presents the current state of the properties, descriptors, and uses of polarization effects, as well as the system constraints necessary to retrieve full polarization information.

In order to fully understand the use of polarization properties of radar targets, a mathematical basis must be established to describe the scattering of electromagnetic waves. Chan [1] reviewed and formalized the most common of the polarization descriptors. These representations included time (and frequency) domain, complex ratio, geometric parameters, Stokes vector, and Poincare sphere. These representations were extended to antenna descriptions and scattering matrices. The most general means of identifying polarization is through the use of the polarization ellipse with axes representing vertical and horizontal polarization. An example of a polarization ellipse is shown in figure 2-1. All types of polarization (i.e. linear, circular, and elliptical) can be shown to be a special case of elliptical polarization and defined by a particular geometry on the polarization ellipse. Four important descriptors are needed to describe the polarization ellipse. **a** is the size of the ellipse and depends on the relative magnitudes of the wave in the horizontal and vertical directions. The angle of tilt, ϕ, describes the tilt of the major axis of the ellipse with respect to an axis of the coordinate frame. τ is the ellipticity of the ellipse. δ is the phase difference, in time, between the orthogonal components of the coordinate frame.

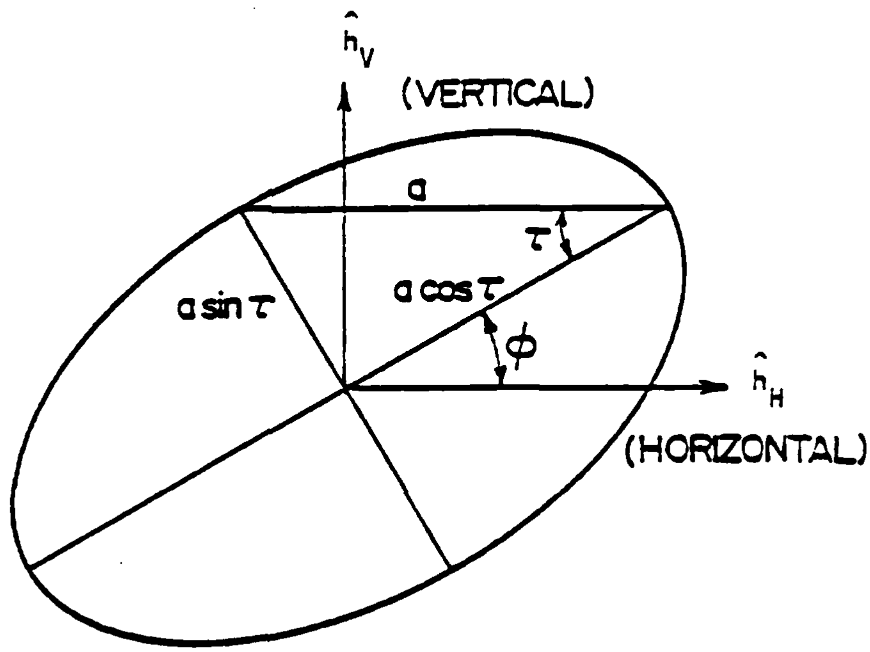

Figure 2-1. Polarization ellipse [1].

The geometric parameters (a, ϕ, τ, and δ) can be combined to form Stokes parameter representation of polarization. The polarization state in Stokes representation is made up of a set of four parameters $\{g_0, g_1, g_2, g_3\}$ or {I, Q, U, V}. Three of the four components are independent and are related to the geometrical description as

$$g_0 = k\, a^2 \tag{2-1}$$

$$g_1 = k\, a^2 \cos 2\tau \cos 2\phi \tag{2-2}$$

$$g_2 = k\, a^2 \cos 2\tau \sin 2\phi \tag{2-3}$$

$$g_3 = k\, a^2 \sin 2\tau \tag{2-4}$$

$$k = (1/2)^{1/2} \tag{2-5}$$

$$g_0^2 = g_1^2 + g_2^2 + g_3^2 \tag{2-6}$$

The Stokes vector $\mathbf{g} = [\, g_0, g_1, g_2, g_3\,]^T$ provides a unique descriptor for each polarization type represented on the polarization ellipse. For example, vertical polarization is represented by $\mathbf{g} = [\,1, -1, 0, 0]$; horizontal polarization by $\mathbf{g} = [\,1, 1, 0, 0]$. Similar representations exist for other linear, circular, and elliptical polarizations.

A graphical means of illustrating polarization is the Poincare sphere. An example of the Poincare sphere is shown in figure 2-2. In the Poincare sphere, normalized Stokes vector components are used to map a particular polarization to a unique point on the sphere. Chan summarized important properties of use of the Poincare sphere to illustrate polarization [1, pg. 32]:

> (a) Each polarization ellipse occupies a unique point on the surface of the sphere. The latitude and longitude of the point are 2τ and 2ϕ respectively.
> (b) Points on the upper hemisphere represent left-handed polarization and conversely, points on the lower hemisphere represent right-handed polarizations.
> (c) The poles represent circular polarizations.
> (d) All points on the equator represent linear polarizations, with horizontal (H) at zero latitude and zero longitude.
> (e) Orthogonal polarizations are antipodal.

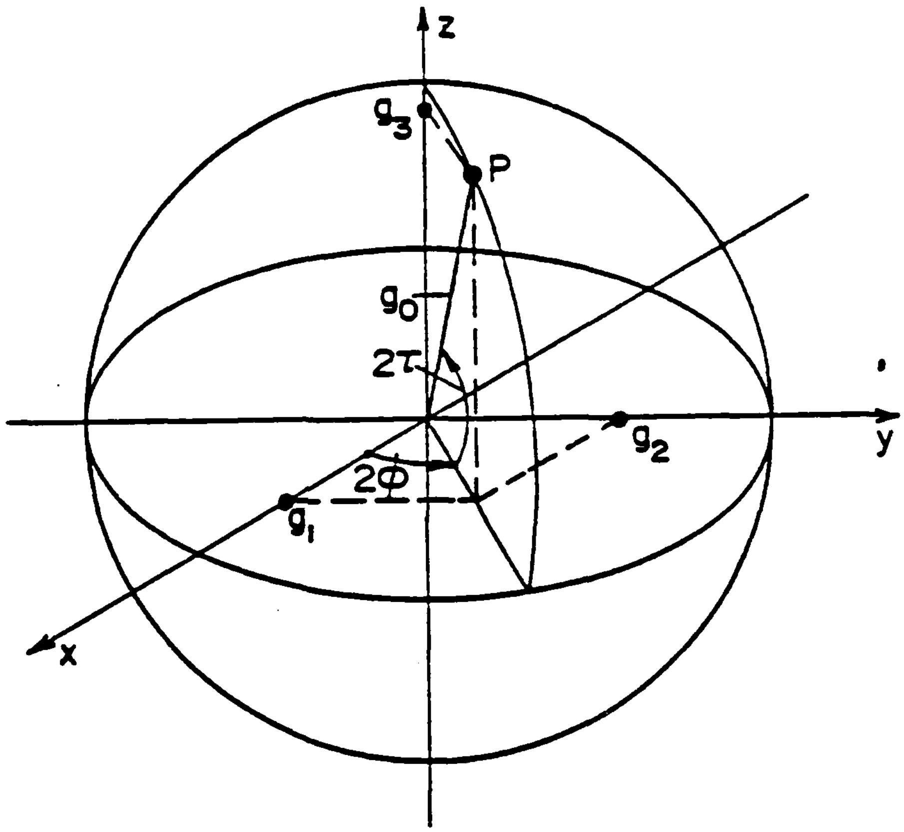

Figure 2-2. Poincare sphere [1].

(f) All points along a given latitude circle represent the same ellipticity (axial ratio).
(g) All points along a given longitude represent the same orientation (tilt) angle with 0° tilt along the zero meridian and 90° tilt along the 180° meridian.

Chan showed the description of scattering from an arbitrary surface can be defined in terms of a scattering matrix, $\boldsymbol{\sigma}$. This matrix is:

$$\sigma_M^o = \begin{bmatrix} \sigma_{VV}^o & \sigma_{VH}^o \\ \sigma_{HV}^o & \sigma_{HH}^o \end{bmatrix} \tag{2-7}$$

All components of $\boldsymbol{\sigma}$ consist of a magnitude and phase. The phase can be absolute or relative to one of the components. In the bistatic case, $\boldsymbol{\sigma}$ is a function of the transmitter incident angle, θ_i, receiver incident angle, θ_S, and receiver azimuth angle, Φ_S.

Kennaugh laid the framework for the use of polarization information in the early 1950's with his research in "Polarization properties of radar reflections" [2]. In the 1970's, Huynen presented a phenomenological approach to the study of polarization properties of radar targets [3-4]. This showed the fundamental importance of connecting the geometries of the target and the transmitting and receiving antennas in order to fully describe the electromagnetic interaction that is taking place.

After the establishment of the existence of important information in polarization data, the varied uses of this information have been detailed by Boerner [5-7] and Poelman [8]. Boerner, in particular, stated that high quality radar polarization data could be used to provide solutions to particular radar problems [8]. These problems include:

(1) Target versus clutter discrimination: Polarization techniques could be used to separate the moving target from clutter existing in it's environment. The clutter could be made up of hostile chaff or surface effects close to low flying aircraft. The required radar system would be required to differentiate between the

relative dynamic, unstable, motion of the target's polarization fork on the Poincare sphere and the slowly changing, more stable polarization fork caused by the clutter.

(2) Target-versus-target and clutter-versus-clutter: Targets and clutter can be separated by their polarization characteristics due to varying frequencies. Relative target and clutter size can be discerned by increasing the broadband capabilities of the radar system and observing the relative difference of motion of the polarization fork.

(3) Target identification: Complete collection of polarization and doppler data from a target, combined with electromagnetic vector inverse processes and back-projection tomographic techniques can be used to uniquely identify and discriminate between targets.

Research has been done to attempt to describe the actual process of depolarization of electromagnetic waves scattered from natural surfaces [9-15]. The depolarization associated with a radar target is usually described as either a surface scattering phenomenon, a volume scattering phenomenon, or a combination of both. Fung provided a general description of the surface and volume scattering from a variety of surfaces [15]. Surface scattering can be summarized [15, pg. 819] as:

> Reflection from a smooth-surface boundary separating two simiinfinite media is called specular reflection and is described by the Fresnel reflection laws. A wave incident upon a rough-surface boundary is partly reflected in the specular direction and partly scattering in all directions. A monostatic radar (transmitter and receiver at the same location) receives the *backscattered* component of the scattered energy. Thus, a monostatic radar would, theoretically, receive no return power from a smooth (specular) surface except for normal incidence.

Therefore, the relative roughness and local incident angles determine how much backscattered energy is returned to the receiver. The measurement of the component of the backscattered energy orthogonal to the polarization of the incident wave is needed to characterize the depolarization process of the scattering surface.

The amount depolarized scattering in a surface or volume can be measured. Blanchard et al. [16] investigated the volumetric depolarization effects in the returns of cross-polarized radar data. They concluded that target soil moisture was an important component in the depolarization process. However, they also had to conclude that not all data analyzed could be used since it was contaminated by the measurement process. Other attempts have been made to match theoretical results to experimentally measured cross polarization data [17-19]. Difficulties have occurred when trying to match the measured cross section data to the values predicted by the theory. Assuming that both theory and measurements are correct leads to the conclusion there must be some phenomena which occurs during the measuring process which contaminates the measured cross section. If the phenomenon can be identified and applied to the physical depolarization measurement, the system dependency of the measurement could be eliminated.

One possible source of error in the measurement is antenna performance as described by Blanchard and Jean [22]. They determined how antenna artifacts corrupt measured data. An important part of antenna bias added to the measurement was antenna feedthrough of signals from the orthogonal input feed of the antenna. When cross polarization information was measured, both like and cross polarization channels contributed to the total measured value, even though only the signal coming through the cross polarized channel was desired. Likewise, signals coming through the cross polarized channel corrupt the like polarization measurement. They described the antenna response with a matrix reflecting the response of each channel to the orthogonal wave. Applying this matrix to the radar equation and solving for the expected scattering cross section, demonstrated the like-polarized scattering coefficient measurement showed very little contamination from the cross-polarized response of the antenna. However, this was not the case for cross-polarization scattering coefficient measurement. In order to measure the cross-polarized scattering coefficient, the receiver's like-pol channel matches the cross-pol

channel of the transmitter. Feedthrough of like-polarized transmitted signals through the cross-polarized response of the like-polarized channel of the receiver significantly altered the cross-polarized measurement. The isolation ratio of the like and cross polarized channels was found to be well described at the boresight of the antenna. That is, antenna manufacturers commonly characterize isolation ratio at boresight, not across the beamwidth. However, as the beamwidth was traversed towards the first null, the isolation ratio was found to decrease. In a typical case, the like- and cross-pol responses could be equal at some point off-axis. A more proper way to describe the isolation ratio would be to integrate the isolation of the channels across the entire beamwidth. The isolation ratio of the antenna must be large in order to assure that the measured scattering coefficient is free of any system (antenna) induced effects.

Another system induced effect, presented by Blanchard, Newton, and Jean [23] was errors that could arise due to the relative geometry of the measurement configuration. Electromagnetic waves propagated from a transmitting antenna are described, in the far-field, as plane wave referenced to the coordinate system of the antenna. The scattering surface is defined in terms of it's own coordinate system. Depolarization was found to occur during the transformation of the wave from the antenna coordinate system to the scattering surface coordinate system. They found that depolarization was a function of beamwidth; as the beamwidth was traversed from boresight to the first null, depolarization due to translation increased. If the coordinate frames of the antenna and surface matched, as can be the case with steerable beam antennas, no depolarization from translation occurred. At nadir, with the antenna pointing directly at the surface, depolarization occurred even at boresight. In fact, the depolarization effect, due to translation, at nadir was found to be of the same magnitude as the cross polarized scattering coefficient being measured.

The literature shows that research has been done to assess the effects of the system on measurements. These effects have been viewed primarily as to their effect in a

monostatic measurement environment. The effect of the system-induced depolarization effects in a bistatic measurement environment has not been established. In a bistatic environment, less difference can occur between cross- and like-pol scattering coefficients. In order to study the bistatic environment, a simulation is required which would incorporate the known system-induced depolarization effects into a transmitter and a receiver allowed to move independently of each other. It is the purpose of this thesis to design such a simulation and extend the theory and simulation results to the bistatic case.

CHAPTER THREE

ANALYTICAL DESCRIPTION

This chapter provides the theoretical understanding and mathematical definition for three depolarization effects which occur in a typical bistatic radar cross section measurement. The three effects to be described are translation depolarization, antenna depolarization, and scattering depolarization. After each effect has been mathematically described, they will be combined into a "system depolarization equation" which can be use to calculate measured scattering coefficients in a computer model.

Translation Depolarization

Translation depolarization is the depolarization effect encountered by not matching the coordinate frame of the transmitting or receiving antenna to that of the scattering surface. Translation depolarization was identified by Blanchard et al. [23]. In a microwave measurement system all polarization vectors must be described with respect to a common, fixed reference point. The best, nonchanging, reference point is the scattering surface. Both receiving and transmitting antennas are defined in reference to the surface so that their relative interaction can be mathematically described.

A typical antenna/surface interaction geometry is shown in figure 3-1. The antenna is located in the (X',Y',Z') coordinate frame. The surface is described by the (X,Y,Z) coordinate frame. The origins of the two coordinate frames are separated by a distance **h**, defined by the height of the surface of the antenna. The Y and Y' axes are always parallel. The antenna can rotate around the Y' axis in order to point the X' axis of

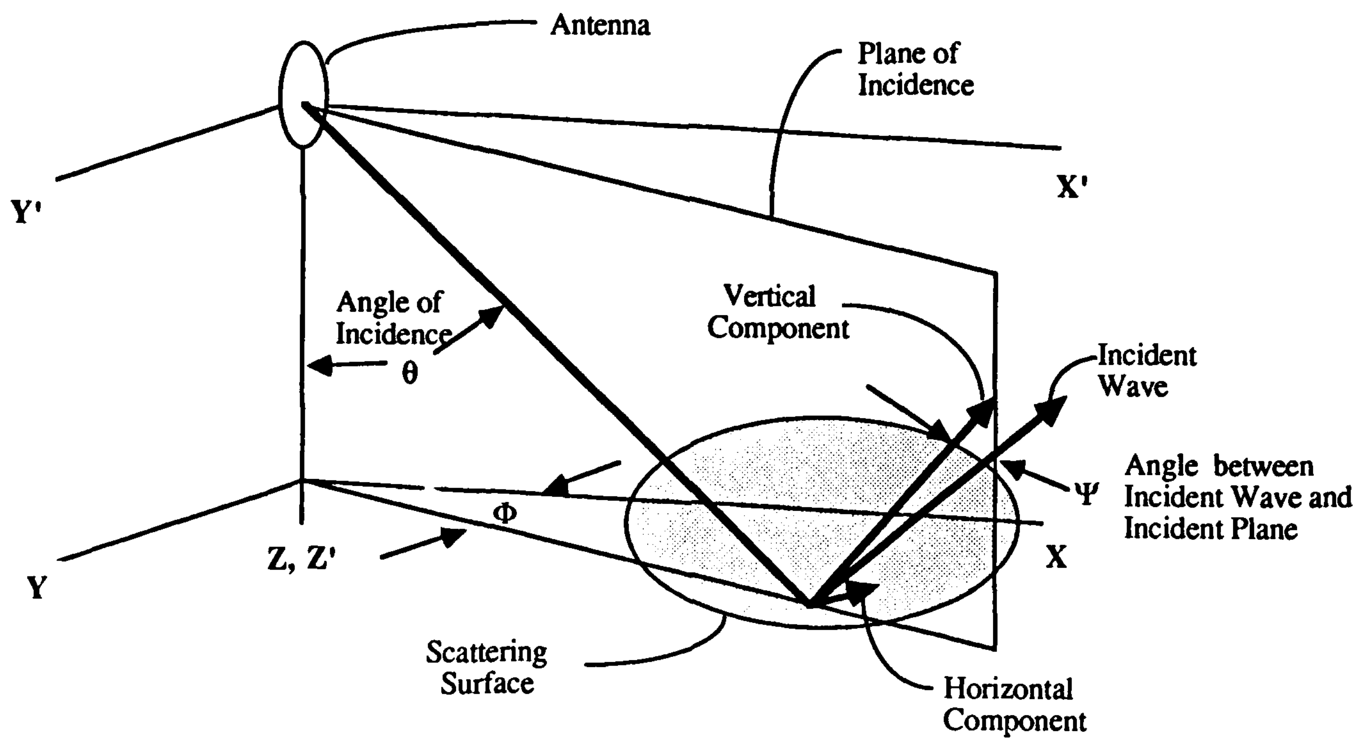

Figure 3-1. Translation Depolarization.

the antenna at a particular point. The amount of rotation of the X'Z' plane about the Y' axis is measured by the angle θ_0. θ_0 is measured from the -Z axis to the X' axis. The angle of incidence of the individual incident wave is measured by the angle θ', measured from the Z' axis. The angle Φ' measures how far the incident wave is off-axis from the main beam, measured from the X' axis ($\Phi' = 0°$).

The antenna angles, θ' and Φ', can be written in terms of the surface coordinate frame angles, θ and Φ. In order to solve for θ, the following intercoordinate frame relationship is required:

$$\theta' = \theta + \left(\frac{\pi}{2} - \theta_0\right) \tag{3-1}$$

thus,

$$\theta = \theta' - \left(\frac{\pi}{2} - \theta_0\right) \tag{3-2}$$

Using this identity, θ is found from

$$\begin{aligned} \cos\theta &= \cos\left(\theta' - \left(\frac{\pi}{2} - \theta_0\right)\right) \\ &= \cos\theta' \sin\theta_0 + \sin\theta' \cos\theta_0 \end{aligned} \tag{3-3}$$

$$\begin{aligned} \sin\theta &= \sin\left(\theta' - \left(\frac{\pi}{2} - \theta_0\right)\right) \\ &= \sin\theta' \sin\theta_0 - \cos\theta' \cos\theta_0 \end{aligned} \tag{3-4}$$

For the angle Φ, the translation between two coplanar coordinate frames is defined from figure 3-2:

$$\begin{bmatrix} \bar{a}_X \\ \bar{a}_Y \\ \bar{a}_Z \end{bmatrix} = \begin{bmatrix} \sin\theta_o & 0 & \cos\theta_o \\ 0 & 1 & 0 \\ -\cos\theta_o & 0 & \sin\theta_o \end{bmatrix} \begin{bmatrix} \bar{a}'_X \\ \bar{a}'_Y \\ \bar{a}'_Z \end{bmatrix} \tag{3-5}$$

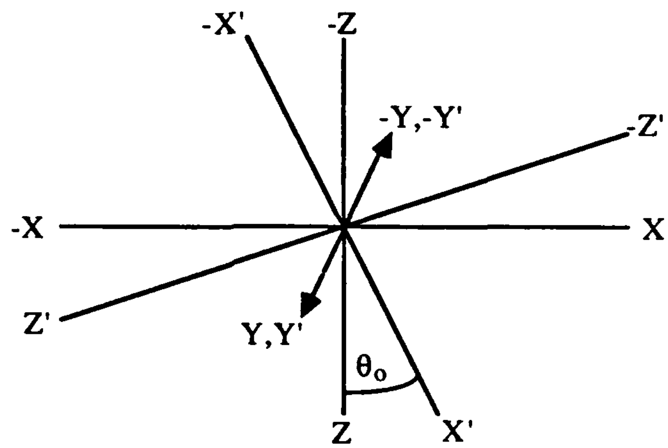

Figure 3-2. Coplanar Translation.

where $(\bar{a}_X, \bar{a}_Y, \bar{a}_Z)$ are unit vectors whose lengths are described in spherical coordinates as:

$$|\bar{a}'_X| = \sin\theta' \cos\Phi' \tag{3-6}$$

$$|\bar{a}'_Y| = \sin\theta' \sin\Phi' \tag{3-7}$$

$$|\bar{a}'_Z| = \cos\theta' \tag{3-8}$$

Now, $\cos\Phi$ is defined in terms of rectangular coordinates as:

$$\cos\Phi = \frac{|\bar{a}_X|}{\sqrt{|\bar{a}_X|^2 + |\bar{a}_Y|^2}}$$

$$= \frac{|\bar{a}'_X|\sin\theta_o + |\bar{a}'_Z|\cos\theta_o}{\sqrt{|\bar{a}_X|^2 + |\bar{a}_Y|^2}}$$

$$= \frac{\sin\theta' \cos\Phi' \sin\theta_o + \cos\theta' \cos\theta_o}{\sqrt{|\bar{a}_X|^2 + |\bar{a}_Y|^2}} \qquad (3\text{-}9)$$

Similarly,

$$\sin\Phi = \frac{|\bar{a}_Y|}{\sqrt{|\bar{a}_X|^2 + |\bar{a}_Y|^2}}$$

$$= \frac{\sin\theta' \sin\Phi'}{\sqrt{|\bar{a}_X|^2 + |\bar{a}_Y|^2}} \qquad (3\text{-}10)$$

Φ is calculated from

$$\tan\Phi = \frac{\sin\theta' \sin\Phi'}{\sin\theta' \cos\Phi' \sin\theta_o + \cos\theta' \cos\theta_o} \qquad (3\text{-}11)$$

The magnitude of the incident wave can be described as the sum of two unit vectors, $\bar{a}'_\Theta$ and $\bar{a}'_\Phi$, that propagate in the $\bar{a}'_R$ direction. This vector must be translated to the surface coordinated frame (unprimed). The angle between the incident wave and the vertical plane of incidence on the surface is defined as Ψ. The relationships between Ψ and the unit vectors (primed and unprimed) in both the θ and Φ directions are:

$$\bar{a}_\theta \bullet \bar{a}'_\theta = \bar{a}_\Phi \bullet \bar{a}'_\Phi = \cos\Psi \tag{3-12}$$

$$\bar{a}_\theta \bullet \bar{a}'_\Phi = -\bar{a}_\Phi \bullet \bar{a}'_\theta = \sin\Psi \tag{3-13}$$

These dot product relationships can be solved with the following spherical vector transformations:

$$\bar{a}_\Phi = -\bar{a}_X \sin\Phi + \bar{a}_Y \cos\Phi \tag{3-14}$$

$$\begin{aligned}
\bar{a}'_\Phi &= -\bar{a}'_X \sin\Phi' + \bar{a}'_Y \cos\Phi' \\
&= -(\bar{a}_X \sin\theta_0 - \bar{a}_Z \cos\theta_0) \sin\Phi' + \bar{a}_Y \cos\Phi' \\
&= -\bar{a}_X \sin\theta_0 \sin\Phi' + \bar{a}_Y \cos\Phi' + \bar{a}_Z \cos\theta_0 \sin\Phi'
\end{aligned} \tag{3-15}$$

The dot product yields

$$\begin{aligned}
\bar{a}_\Phi \bullet \bar{a}'_\Phi &= \cos\Psi \\
&= \sin\theta_0 \sin\Phi \sin\Phi' + \cos\Phi \cos\Phi'
\end{aligned} \tag{3-16}$$

A translation matrix, **T**, can now be defined which completely describes the transformation needed to get from the antenna coordinate frame to the surface coordinate frame. **T** is defined as:

$$\mathbf{T} = \begin{bmatrix} \cos\Psi & \sin\Psi \\ -\sin\Psi & \cos\Psi \end{bmatrix} \tag{3-17}$$

The following transformation now holds:

$$\begin{bmatrix} \bar{a}_\theta \\ \bar{a}_\Phi \end{bmatrix} = T \begin{bmatrix} \bar{a}'_\theta \\ \bar{a}'_\Phi \end{bmatrix} \tag{3-18}$$

The inverse relationship, transforming from surface coordinates to the antenna frame, is simply the inverse of equation (3-18):

$$\begin{bmatrix} \bar{a}'_\theta \\ \bar{a}'_\Phi \end{bmatrix} = T^{-1} \begin{bmatrix} \bar{a}_\theta \\ \bar{a}_\Phi \end{bmatrix} \tag{3-19}$$

Antenna Depolarization

Antenna feed through effects, or antenna depolarization, is depolarization caused by imperfect illumination of the transmitting or receiving antennas. The effects of antenna depolarization have been researched by Blanchard and Jean [22]. They developed a mathematical basis for including cross polarization terms in the radiation pattern of the antenna. Logically, a perfect, or "ideal", antenna would have no coupling of vertical and horizontal transmit or receive modes. However, the real world environment does not have access to perfect antennas. Blanchard and Jean characterized the term "polarization isolation ratio" to define the error caused by cross polarization effects on a linear polarized antenna. They showed that at boresight (0° offaxis) of the antenna pattern, the cross polarized return had little affect on the system. However, the cross polarized returns showed a significant effect as the pattern was traversed from boresight to the edge of the pattern. The polarization response of a typical antenna is shown in figure 3-3. In this figure, the light line represents the antenna response for the incoming (or outgoing) polarization of the wave

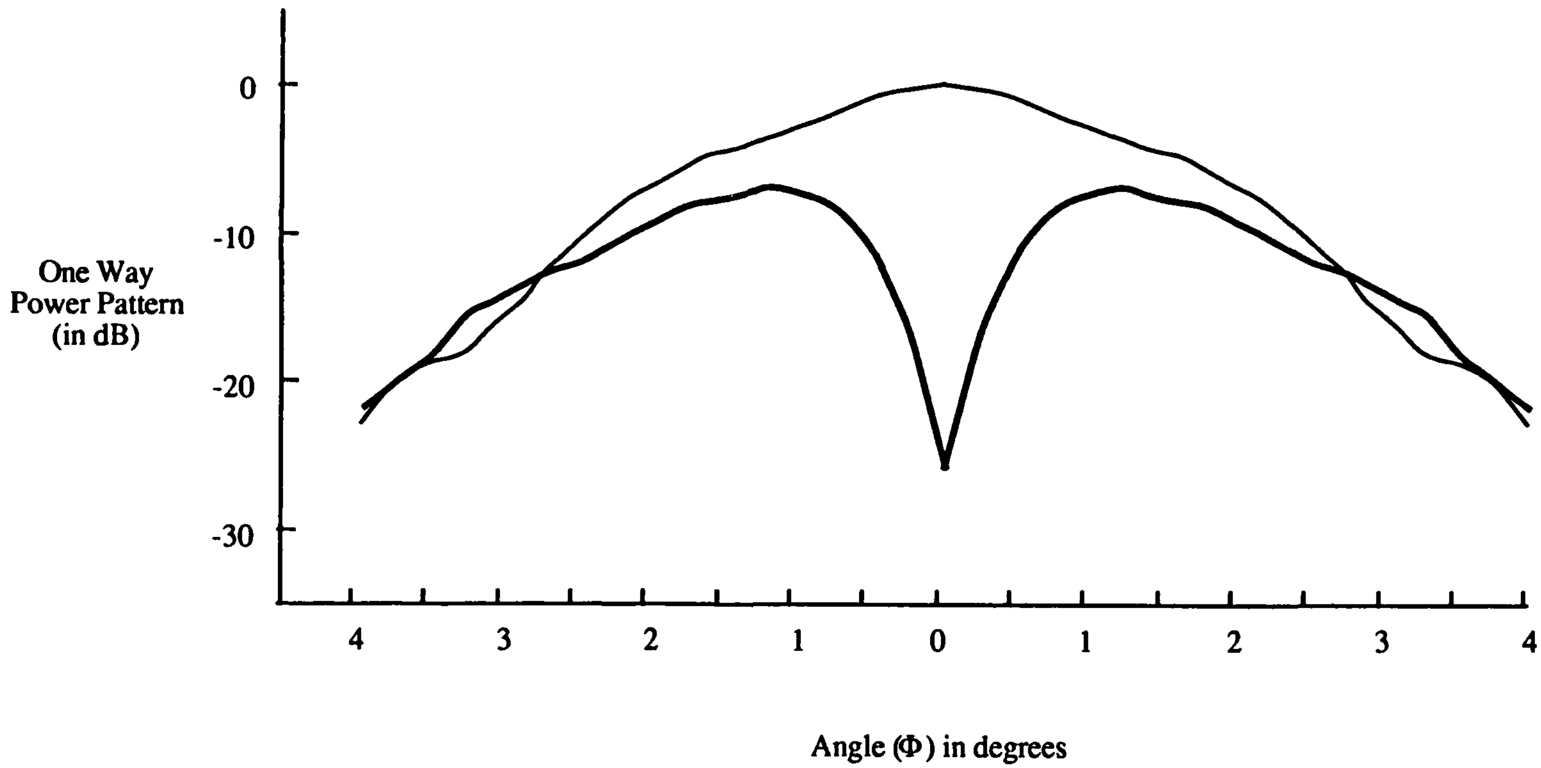

Figure 3-3. One way antenna power pattern.
Light Line - Like polarization response.
Dark Line - Cross polarization response.

which matches the antenna. The dark line shows the antenna response to the orthogonal wave. As can be seen, the orthogonal polarization will contribute to the off-axis response of the antenna. Blanchard and Jean determined that the polarization isolation ratio was a function of the beamwidth of the antenna. Cross polarization response added considerable ambiguity to measurements appearing off the main boresight axis.

The response of an antenna can be described by the matrix **F**, defined as:

$$\mathbf{F} = \begin{bmatrix} f_{VV} & f_{VH} \\ f_{HV} & f_{HH} \end{bmatrix} \tag{3-20}$$

where the matrix terms are defined as follows:

f_{VV} = vertical response of antenna to vertical signal

f_{VH} = vertical response of antenna to horizontal signal

f_{HV} = horizontal response of antenna to vertical signal

f_{HH} = horizontal response of antenna to horizontal signal

The matrix **F** represents the response of the antenna to all polarizations for all points in the beamwidth. In the bistatic environment, two **F** matrices are needed: $\mathbf{F_T}$, for the transmitting antenna, and $\mathbf{F_R}$, for the receiving antenna.

Scattering Depolarization

A third source of depolarization is the scattering surface itself. The scattering effect from a surface seen through a bistatic geometry is significantly different than the response of the surface in a monostatic geometry. A scattering matrix, $\boldsymbol{\sigma^o}$, can be defined

to represent the scattering response of the surface to all polarizations. σ^o is described by:

$$\sigma^o_M = \begin{bmatrix} \sigma^o_{VV} & \sigma^o_{VH} \\ \sigma^o_{HV} & \sigma^o_{HH} \end{bmatrix} \tag{3-21}$$

where

σ^o_{VV} : vertical scattering of vertically polarized waves

σ^o_{VH} : vertical scattering of horizontally polarized waves

σ^o_{HV} : horizontal scattering of vertically polarized waves

σ^o_{HH} : horizontal scattering of horizontally polarized waves

In order to fill this matrix, a scattering model must be selected which obtains practical results with minimum computational effort. Such a model exists and is described in Ulaby et al. [15]. The model in question is a special case of the Kirchoff scattering model using scalar approximation and exponential correlation. This model exhibits the correct angular trend expected for bistatic scattering and provides results with relative computational ease. The bistatic scattering coefficient, $\sigma^o{}_{pq}$, is described as:

$$\sigma^o_{pqn} = \frac{k^2 \, |a_0|^2}{4\pi} \exp(-q_Z^2 \sigma^2)$$

$$\sum_{n=1}^{\infty} \frac{(q_Z^2 \sigma^2)^n}{n!} \iint_{-\infty}^{\infty} \rho^n \exp\left[j q_X u + j q_Y v\right] du\, dv \tag{3-22}$$

where

k : wave number

σ : standard deviation of surface heights

ρ : surface correlation distribution

$$q_X = k\,(\sin\theta_S\cos\theta_S - \sin\theta_T\cos\Phi_T)$$
$$q_Y = k\,(\sin\theta_S\sin\theta_S - \sin\theta_T\sin\Phi_T)$$
$$q_Z = k\,(\cos\theta_S + \cos\Phi_T)$$
$$q_Z{}^2 = q_X{}^2 + q_Y{}^2$$

The surface correlation distribution, ρ, is exponential in this approximation as shown below:

$$\rho = \exp\,(-\zeta/l) \qquad (3\text{-}23)$$

where

l : correlation distance of surface

$\zeta^2 = u^2 + v^2$

Using this substitution, the integral in the scattering coefficient equation can be simplified to a zeroth order Bessel function. The equation can then be furthered simplified to:

$$\sigma^o_{pq} = \frac{k^2\,|a_o|^2}{2\,l}\exp(-q_Z^2\sigma^2)\sum_{n=1}^{\infty}\frac{(q_Z^2\sigma^2)^n}{(n-1)!}\left[\left(\frac{n}{l}\right)^2 + q_X^2 + q_Y^2\right]^{-3/2}$$

(3-24)

The individual terms of the scattering matrix are found by substituting the appropriate equation for a_o from the following values of p and q:

$$pq = HH\ :\quad a_o = -\Gamma_\perp\,(\cos\theta_T + \cos\theta_S)\cos(\Phi_S - \Phi_T) \qquad (3\text{-}25)$$

$$pq = VH\ :\quad a_o = -\Gamma_\perp\,(1 + \cos\theta_T\cos\theta_S)\sin(\Phi_S - \Phi_T) \qquad (3\text{-}26)$$

$$pq = VV\ :\quad a_o = \Gamma_\parallel\,(\cos\theta_T + \cos\theta_S)\cos(\Phi_S - \Phi_T) \qquad (3\text{-}27)$$

$$pq = HV\ :\quad a_o = -\Gamma_\parallel\,(1 + \cos\theta_T\cos\theta_S)\sin(\Phi_S - \Phi_T) \qquad (3\text{-}28)$$

$\Gamma_{\parallel}$ and $\Gamma_{\perp}$ are the Fresnel reflection coefficients for parallel and perpendicular polarization, respectively.

System Depolarization Equation

These matrices can be combined in the radar equation to assess their overall effect on the measurement of the scattering coefficients of an arbitrary surface. The radar equation can be rewritten with the matrix components as:

$$P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi)^3} \int_{A_{TOT}} \frac{F_T \, T_T \, \sigma^o_T \, T_R \, F^T_R}{R^2_T \, R^2_R} \, dA \qquad (3\text{-}29)$$

A system constant can be defined to aid in the normalization of this equation. The system constant, K_S, is

$$K_S = \frac{P_T G_T G_R \lambda^2 A_{TOT}}{(4\pi)^3 \, R^2_{Tnom} R^2_{Rnom}} \qquad (3\text{-}30)$$

K_S and $\mathbf{P_R}$ can be combined to form the expected, or measured, scattering coefficient, $\sigma^o{}_M$. This normalization results in:

$$\sigma^o_M = \frac{P_R}{K_S} \qquad (3\text{-}31)$$

$$\sigma^o_M = \frac{R^2_{Tnom} R^2_{Rnom}}{A_{TOT}} \int_{A_T} \frac{F_T \, T_T \, \sigma^o_T \, T_R \, F^T_R}{R^2_T \, R^2_R} \, dA \qquad (3\text{-}32)$$

Converting the integration over the beamwidth as described in equation 3-32 to a summation of the effect on discrete cells located within the intersection of the transmitter and receiver beamwidths results in the following equation:

$$\sigma^o_M = \frac{R^2_{Tnom} R^2_{Rnom}}{A_{TOT}} \sum_{cells} \frac{F_T\, T_T\, \sigma^o_T\, T_R\, F^T_R\, \Delta A}{R^2_T\, R^2_R} \tag{3-33}$$

The result of this summation is the approximation of the measured result to the theoretical scattering coefficients that exist on the scattering surface with the antenna and translation depolarization matrices acting as attenuators or amplifiers to the surface.

The matrix multiplications can be simplified to isolate the basic effect that contribute to the measurement of a like and cross polarization scatterer. One assumption that can be made to help this simplification is that:

$$\cos\Psi \approx 1 \quad \text{and} \quad \sin\Psi \approx 0 \tag{3-34}$$

This assumption holds very closely for all incidents angles except near nadir (0° incidence). With this assumption, the calculation of the measured like and cross polarization scattering coefficients reduces to the following equations:

$$\begin{aligned} \sigma^o_{HHm} \approx\ & f_{RHH}\left[\sigma^o_{VH} f_{THV} + \sigma^o_{HH} f_{THH}\right] \\ & + f_{RHV}\left[\sigma^o_{VV} f_{THV} + \sigma^o_{HV} f_{THH}\right] \end{aligned} \tag{3-35}$$

$$\begin{aligned} \sigma^o_{HVm} \approx\ & f_{RVV}\left[\sigma^o_{VH} f_{THV} + \sigma^o_{HH} f_{THH}\right] \\ & + f_{RVH}\left[\sigma^o_{VV} f_{THV} + \sigma^o_{HV} f_{THH}\right] \end{aligned} \tag{3-36}$$

Analysis of these equations shows that the major effect expected in system depolarization is attributable to the cross-polarization feedthrough found in imperfect antennas. Knowledge of the cross-polarization feedthrough of the transmitter and receiver is necessary in order to properly acknowledge the source of measured cross polarized scattering coefficients.

CHAPTER FOUR

MODEL DESCRIPTION

A computer simulation was designed to explore the combined effect of these depolarization phenomena associated with coordinate frame translation, antenna feed-through effects, and scattering. The computer program was written in FORTRAN '77 and was run on a VAX 11/780. The program simulates the surface interaction of a transmitter and a receiver, which are oriented in an arbitrary bistatic geometry. The program models this interaction by taking a "snap-shot" in time and freezing the antenna patterns associated with both the transmitting and receiving antennas. The power received at the receiver is calculated and used to find a measured value for the scattering coefficient of the surface. This measured value can then be compared with the actual, or theoretical, value for the scattering coefficient which actually exists on the surface. This chapter will describe, in detail, the operation of the computer simulation as seen by "user".

The simulation consists of two main processing modules, DATAINPUT and SYSEFF. DATAINPUT, as the name implies, provides a means for inputing all system parametric information into data files. The user has the capability to input the following data files:

(1) antenna patterns

(2) terrain scattering coefficients

(3) run set data

The antenna patterns are input through the subroutine ANTIN. The user can name the antenna with an arbitrary six character code. The user is then queried on the parametric aspects of the antenna pattern. First, the beamwidth, in degrees, of the antenna

is entered. The incremental spacing across the beam is then input. The incremental spacing is determined by the resolution of the known data values of the actual antenna pattern across the beamwidth. The user now inputs the actual antenna pattern. Two patterns are required, the like-polarization (like-pol) pattern and the cross-polarization (cross-pol) pattern. The user inputs the one-way power pattern values (in dB) found across the pattern at $\theta = 0°$ and values of Φ starting at 0° up to one half of the beamwidth. The incremental resolution determines the spacing of the values. Figure 4-1 illustrates the segment of the antenna pattern data values input by the user. The antenna pattern is assumed to be

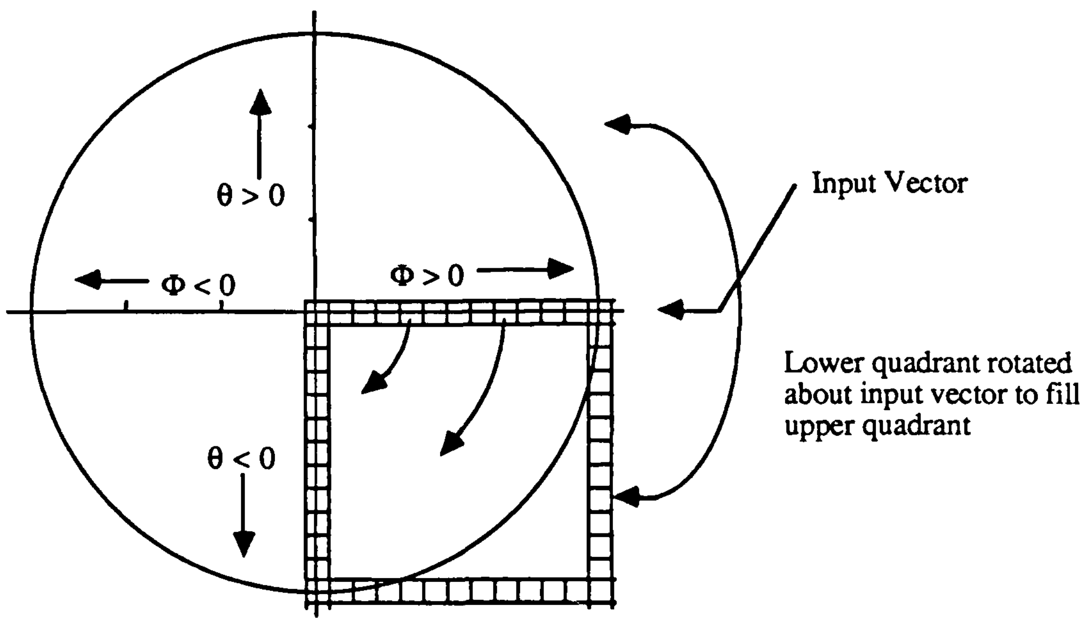

Figure 4-1. Antenna Pattern Input Scheme.

symmetric about the boresight of the antenna ($\theta = 0°$, $\Phi = 0°$). This assumption is used to fill the lower quadrant of the pattern by rotating the input vector through -90°. Two value linear interpolation is used to calculated values in the the quadrant that are an equivalent distance from the origin. The lower right quadrant, once it has been completely filled, is

copied directly to the upper right quadrant to fill half of the antenna pattern. The matrix, consisting of the upper and lower right quadrant of the antenna pattern for both like- and cross-pol, is then written to a file for storage.

Terrain information is also entered with the DATAINPUT program. Two different types of terrain are used by the model. The first is monostatic terrain. For this type of geometry, the assumptions are made that the terrain scatterers act as isotropic point sources and that the receiving and transmitting antennas are in the same location. The second is bistatic terrain Bistatic terrain variables are assumed to change over angles of incidence and azimuth in response to the various transmitter-to-scatterer-to-receiver geometries that occur when the transmitter and receiver are in different locations. Two different subroutines input the scattering coefficients, MONOTERRAIN for the monostatic environment and BISTATTERRAIN for the bistatic environment.

MONOTERRAIN allows the user to enter the complex scattering coefficient matrix, $\boldsymbol{\sigma}^0$, for the surface. The user enters a six character code name for the terrain file about to be entered. Next, the four complex components of the $\boldsymbol{\sigma}^0$ matrix are entered. These are σ_{VV}, σ_{VH}, σ_{HV}, and σ_{HH}. The numbers are entered as a magnitude (in dB) and a phase (measured with respect to σ_{VV}). Only one scattering matrix can be entered to represent the entire surface.

The user accesses BISTATTERRAIN to input scattering coefficient data for a bistatic environment. The user first enters a six character code to identify the data set. Then the user enters the azimuth angle of the receiver and the incident angle of the transmitter. The model will only vary the incident angle of the receiver for a specified azimuth and transmitter incident angle. Additional data files are required in order to store data at other receiver azimuths or transmitter incidents. The user then enters a separate scattering coefficient matrix, $\boldsymbol{\sigma}^0$, for each possible receiver incident angle starting at 0°, ending at 80°, incremented by 10°. The four scattering coefficient matrix components, as described for the

MONOTERRAIN subroutine, are entered as before.

The last function of DATAINPUT is to allow the user to define a "run set" for the model to operate on. A run set is a file containing all the parametric data information needed by the model during it's execution. Since the model is designed to be as generic as possible, all outside system, geometry, and terrain information is listed here. Subroutine RUNIN controls the input of this information. The user first enters an eight character code word to identify this run set. The user is then asked two questions which refer particularly to the execution of the model. The first is to define matrix size. This size refers to the actual dimension of the matrices used determine discrete positions on the surface. The higher dimension of the matrix, the greater the resolution of each individual cell in the matrix, but also, the greater execution time required to run the model. The next answer the user is required to enter is the "X:Y" ratio. This ration describes the relative size of the cells in the X direction with respect to the size of the cells in the Y direction. Resolution in each of the directions can thus be changed.

Antenna information is gathered next. The name of the files containing the antenna patterns of the transmitter and the receiver are entered by the user. The user also enters the polarization of the antenna, either "H" for horizontal, or "V" for vertical.

The user must now enter the following information about the relative positioning of the receiver and transmitter:

(1) bistatic or monostatic geometry

(2) transmitter

(a) antenna inclination angle, θ_0, in degrees

(b) ground distance to target, in meters

(c) height above surface, in meters

(3) receiver

(a) antenna inclination angle

(b) slant distance to target

(c) minimum and maximum incident angle

(d) azimuth angle (transmitter assumed to be at 0°)

(4) terrain file name

After all parametric information has been entered it is stored in a data file until needed by the execution of the model.

The actual model is called SYSEFF. This computer program inputs all parametric information stored by DATAINPUT and executes the model accordingly. SYSEFF acts as a stand alone program which can execute without user intervention.

The first step SYSEFF undertakes is to determine the input file to be used for execution. The subroutine RUNIN accepts an eight character code name which is used to identify the input file. The input file is opened and all parametric variable values are read from this file. On the basis of the transmitter, receiver, and terrain file identifiers input, antenna patterns and scattering coefficients are input from their respective files. RUNIN then sets up the looping mode of the model to execute the model the requested number of times. The architectural structure of the looping mode appears as:

(I) Rx antenna inclination angles

(A) Rx incident angles

(1) Execute model (subroutine RUNONE)

Subroutine RUNONE executes the model one time for a specific positioning of the transmitter and receiver. The first operation of RUNONE is to "paint", or translate, the terrain with the pattern of the transmitting antenna. This is done with the subroutine PAINT. The assumption that the antenna pattern is symmetric through the center line defined by $\Phi = 0°$ is used to make these calculations. Only half of the antenna pattern is "painted" on the ground. Figure 4-2 shows a simple rendition of the antenna pattern being translated to the surface.

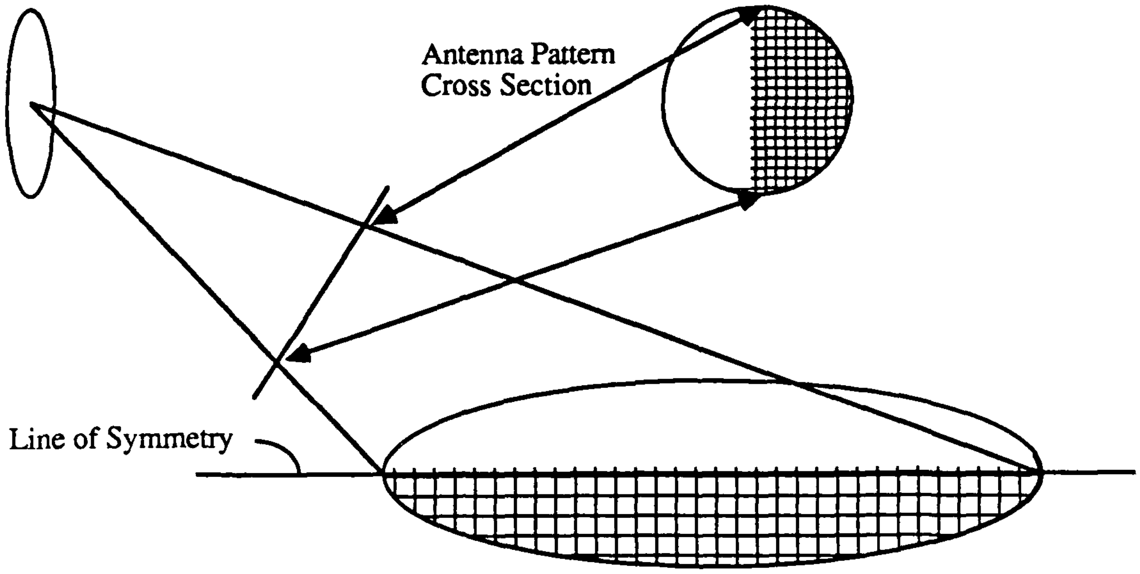

Figure 4-2. Antenna-to-Surface Pattern Translation.

The surface is divided into "cells", each corresponding to a location in the surface matrix. The center of the pattern is assumed to coincide with the center of the surface matrix. PAINT steps through each cell, determining whether that particular cell is located within the beam of the antenna. If the cell is located in the beam of the antenna, the following information is calculated for that cell:

1. θ and Φ with respect to surface coordinate frame

2. θ' and Φ' with respect to the antenna coordinate frame

3. Like-pol and cross-pol responses of the antenna (addresses into the antenna pattern matrix are θ' and Φ', four point interpolation is used to calculate intermediate values)

4. Slant range from the antenna to the cell

All this information is collected in a COMMON area for access by other parts of the model.

After the antenna pattern is "painted" on the ground, the pattern is folded along it's access of symmetry in order to complete the entire pattern on the surface. This is

accomplished with the subroutine DOUBLE.

Once the transmitting antenna is "painted" and "doubled" the process continues identically for the receiving antenna. For the receiving antenna, however, an additional item must be taken under consideration following the "doubling" of the pattern. The transmitter is assumed to be at 0° azimuth. The receiver can move about in azimuth for a bistatic geometry. The receiver pattern is now rotated about the center of the surface matrix to it's correct azimuth angle. This rotation is shown in figure 4-3.

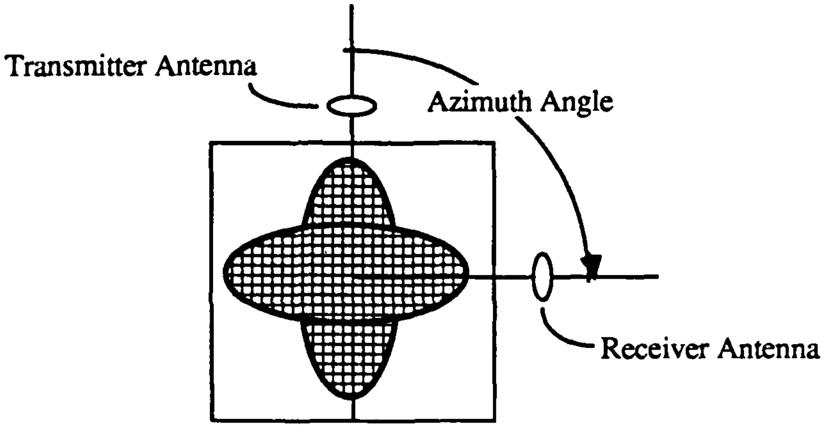

Figure 4-3. Receiver Antenna Rotation.

After both transmitter antenna patterns have been placed on the ground and rotated to the correct orientation, the core of the model is executed. The subroutine INTEGRATE applies the radar equation derived in chapter three (equation 3-33) to each and every cell on the surface. The five complex matrices ($\mathbf{F_T}$, $\mathbf{T_T}$, $\boldsymbol{\sigma^o}$, $\mathbf{T_R}$, and $\mathbf{F_R}$) are all known for each cell. Complex matrix multiplication is used to combine the matrices. Cells not having both the transmitter and receiver pattern are skipped. The result of the multiplication, P_R, is accumulated for each cell, resulting in a discrete integration of the power received over the intersection of the transmitter and receiver antenna patterns. The system normalization constant, K_S, is also calculated for each cell and accumulated. After

the effect of all cells has been included, the measured scattering coefficient for the surface is calculated by dividing K_S into P_R.

Appendix A contains the following information about DATAINPUT and SYSEFF useful to the user:

(1) computer listing of DATAINPUT

(2) computer listing of SYSEFF

(3) sample interactive session showing input techniques

(4) output results expected from inputs supplied at interactive session

This chapter described a computer model designed to simulate the effect of system depolarization effects in a bistatic environment. The model was written in a generic form to allow the user considerable flexibility in the choice of antennas and overall measuring system geometry.

CHAPTER FIVE

RESULTS

This chapter describes the experiments conducted with the SYSEFF model and the results from these experiments. The experiments were designed specifically to determine the effect of either translation or antenna depolarization on the bistatic measurements of scattering coefficients on an arbitrary surface.

The theoretical experiments run with SYSEFF, were designed to determine a measured scattering coefficient value of a specified surface as measured from a variety of bistatic geometry positions. Specifically, the positioning of the receiver and transmitter were altered to discover what effect (if any) translation and antenna depolarization had on measurements of like and cross polarized scattering from a surface. The transmitting and receiving antennas patterns were varied, as well, to reveal the effect of the antenna patterns on the measurements.

The theoretical bistatic surface scattering coefficients used in the actual test runs were the output of the bistatic scattering model developed by A. K. Fung [15]. This model was described in chapter three, Analytical Description. The bistatic scattering coefficients were calculated for the following bistatic geometries in order to establish the expected scattering coefficient matrix for each geometry.

transmitter azimuth, Φ_T	: 0°
transmitter incidence, θ_T	: 30°,60°
receiver azimuth, Φ_S	: 0°,45°,90°,135°,180°
receiver incidence, θ_S	: 0° - 80°

normalized rms surface height, $k\sigma$: 0.3

normalized surface height correlation length, kl : 8

The results of these calculations for $\theta_T = 60°$ are shown in figures 5-1 through 5-3. The results for $\theta_T = 30°$ are shown in appendix B. Each plot shows the theoretical scattering coefficients expected in the direction of the scattering azimuth, Φ_S. The following plots are combined: 0° and 180°, 45° and 135° (225°), and ±90°. A review of the shapes of the various plots shows the following characteristics (for both 30° and 60° transmitter incidence, θ_T). Strong forward scattering of like polarized components is found on the $\Phi_S = 0°$, 180° plot (figure 5-1) at approximately the angle as the transmitter incident angle, θ_T. No scattering of cross polarized components is expected at these scattering azimuth angles. On the $\Phi_S = 45°$, 225° plot (figure 5-2), scattering of all four like and cross polarized components is predicted. On the $\Phi_S = \pm 90°$ (figure 5-3) only cross polarized scattering is expected. This data was used as the scattering matrices to scatter the incoming planes waves from the transmitter.

Three different antennas were used for the test runs. The transmitter and receiver were assumed to have identical antennas for each run. The first was an ideal antenna, having 2.5° beamwidth with 0 dB like polarization and -100 dB cross polarization response across the beamwidth. The second antenna was a simulated realization of an actual antenna. The antenna pattern of this antenna is shown in figure 3-3. The half-power beamwidth of this antenna was 2.5°. The third antenna was a hybrid combination of the ideal and the real. This antenna had perfect (0 dB) like polarization response across the 2.5° beamwidth then fell off to constant -15 dB sidelobes out to the full 10° beamwidth. The cross polarization response of this antenna was a constant -20 dB across the entire beamwidth. The antenna patterns for the ideal and hybrid antennas are contained in appendix B.

The transmitter was located at a slant range of 10,000 meters and an incident angles of 30° and 60° on the 0° azimuth. The receiver was also located at a slant range of

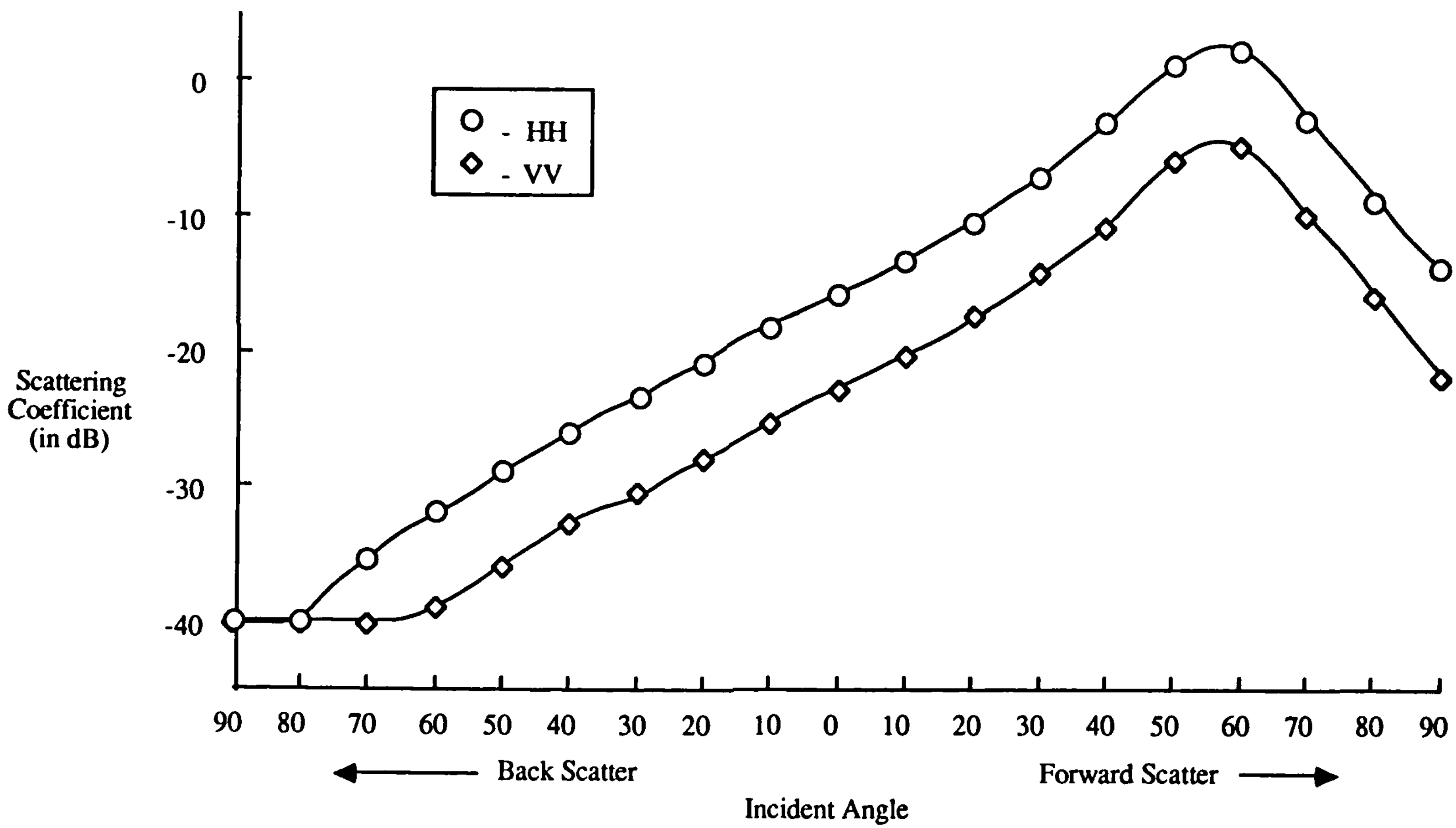

Figure 5-1. Variation of the Bistatic Scattering Coefficient as a Function of Receiver Incident Angle: Receiver Azimuth = 0°,180°, Transmitter Incidence = 60°.

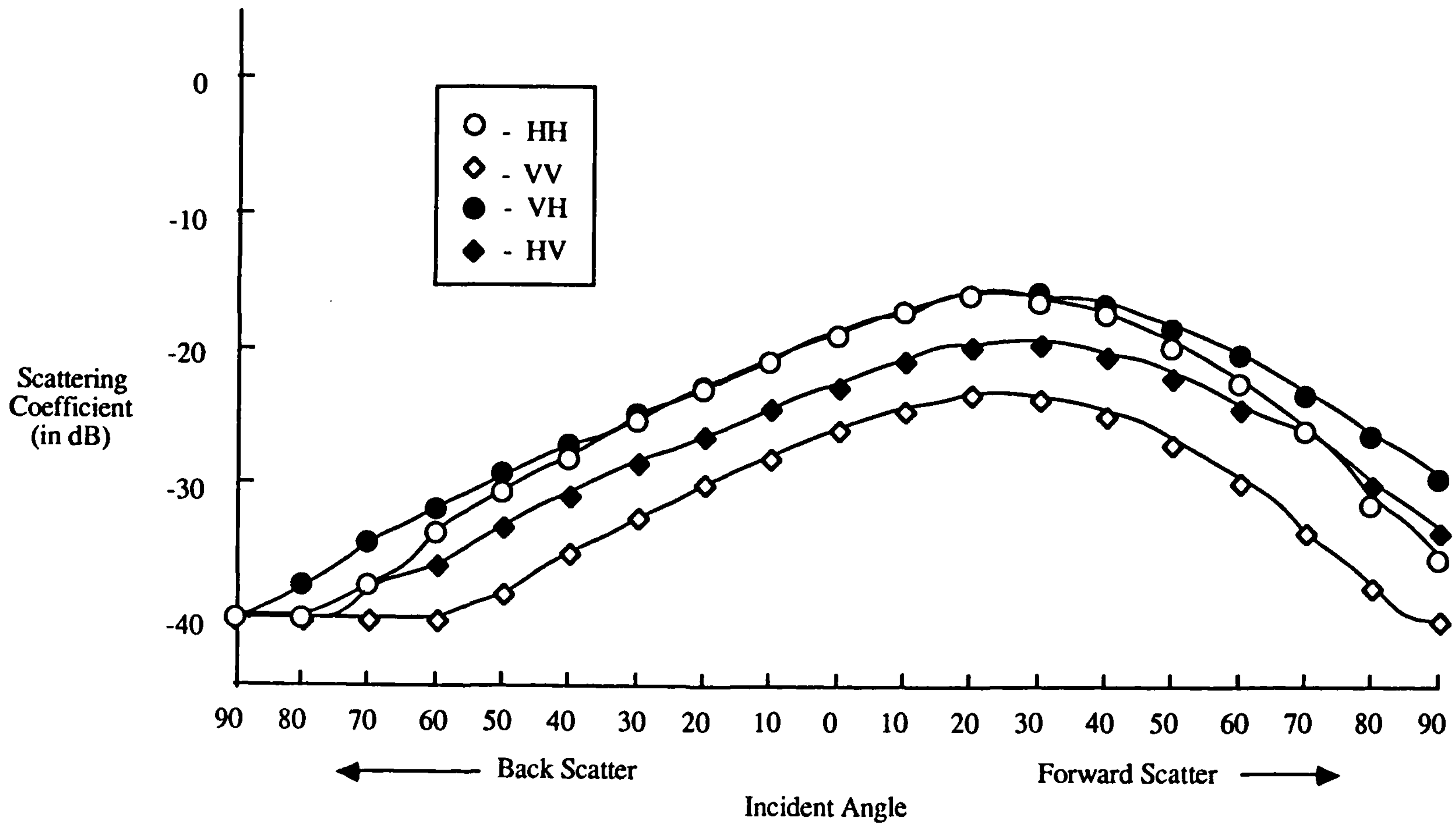

Figure 5-2. Variation of the Bistatic Scattering Coefficient as a Function of Receiver Incident Angle: Receiver Azimuth = 45°,225°, Transmitter Incidence = 60°.

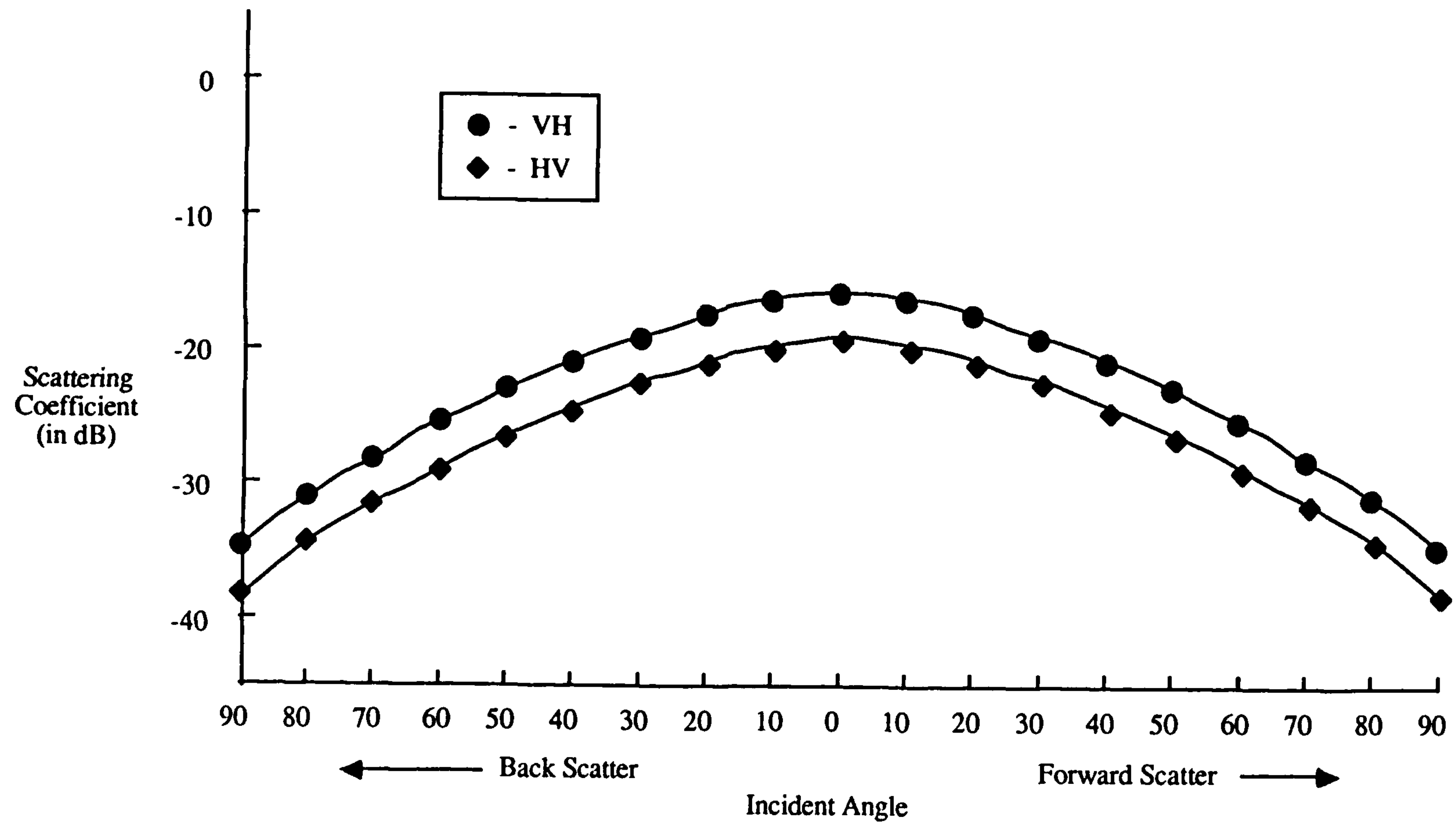

Figure 5-3. Variation of the Bistatic Scattering Coefficient as a Function of Receiver Incident Angle: Receiver Azimuth = 90°,270°, Transmitter Incidence = 60°.

10,000 meters but varied in azimuth and incidence angles. The receiver was moved through 0°, 45°, 90°, 135°, and 180° azimuth. At each azimuth, the receiver was taken through 0° - 80° incident angles. Both transmitter and receiver were assumed to be pointing directly at the same cell, thus as azimuth angles changed, the receiver pattern on the ground rotated around this central cell.

For the measurement of the like polarization scattering coefficient, both the transmitting and receiving antennas were horizontally polarized. For the cross polarization measurement, the transmitting antenna was horizontally polarized and the receiving antenna was vertically polarized. Both antennas were polarized with respect to their respective planes of incidence.

The results of the like polarization test measurements when the transmitter is at 60° incidence angle are shown in figures 5-4 through 5-8. The results for the transmitter incident angle of 30° are located in appendix C. A comparison of the theoretical scattering coefficients and the measured scattering coefficients for the like polarization shows that little significant difference can be seen between the expected and actual results except in two circumstances. In figure 5-4 ($\Phi_S = 0°$), all antennas measure the correct like-pol scattering coefficient for all angles except at nadir ($\theta_S = 0°$). At nadir, all antennas measure approximately 3 dB below the expected scattering coefficient. Since all antennas show this effect, it is caused by the large translation depolarization that can happen at nadir for even very small half-power beamwidths, in this case, 2.5°. Figure 5-5 ($\Phi_S = 45°$) shows a very similar curve to the previous curve. The antennas once again were able to measure the like-pol scattering coefficient accurately for all incident angles except nadir. At nadir, the ideal antenna had an error of approximately 6 dB. The ideal antenna had the greatest error since all of the available power was located within it's half-power beamwidth and depolarized by the translation effect. At 90° azimuth (figure 5-6), like-pol scattering is not expected. The input for the scattering coefficient was set at -100 dB. However, like

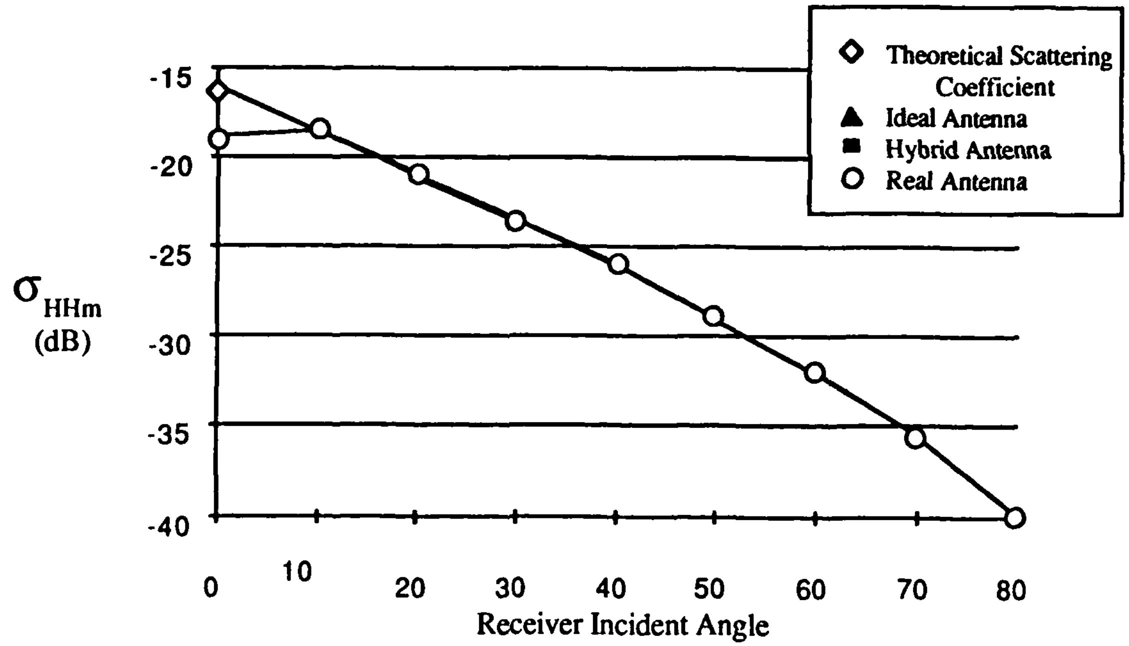

Figure 5-4. Measured Like-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 0°, Transmitter Incidence = 60°.

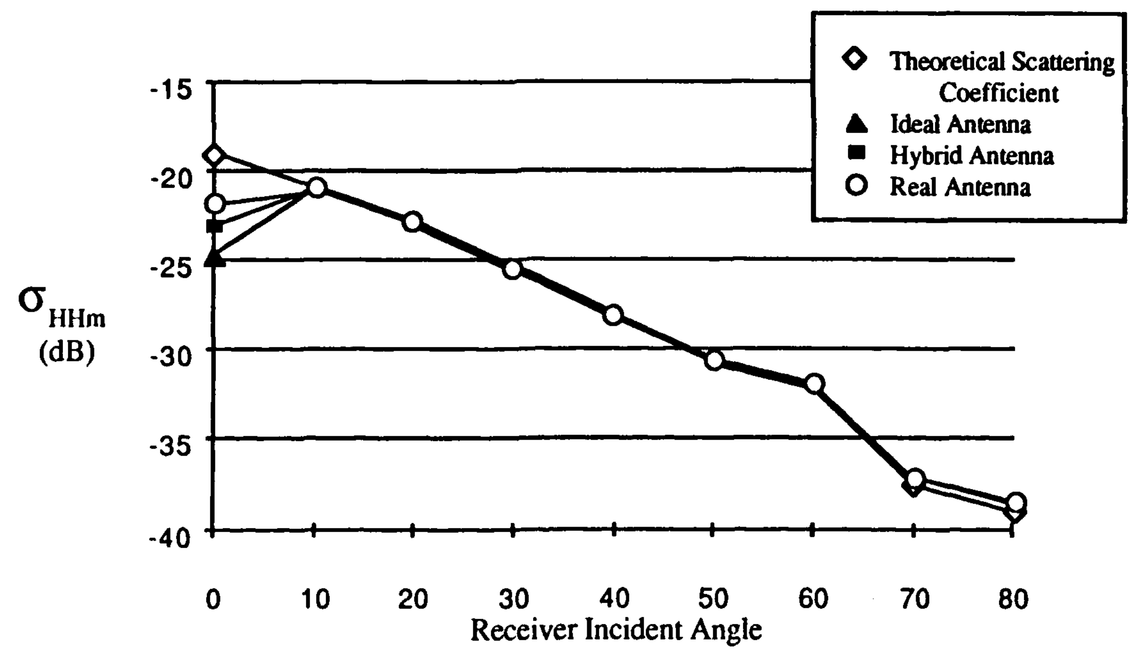

Figure 5-5. Measured Like-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 45°, Transmitter Incidence = 60°.

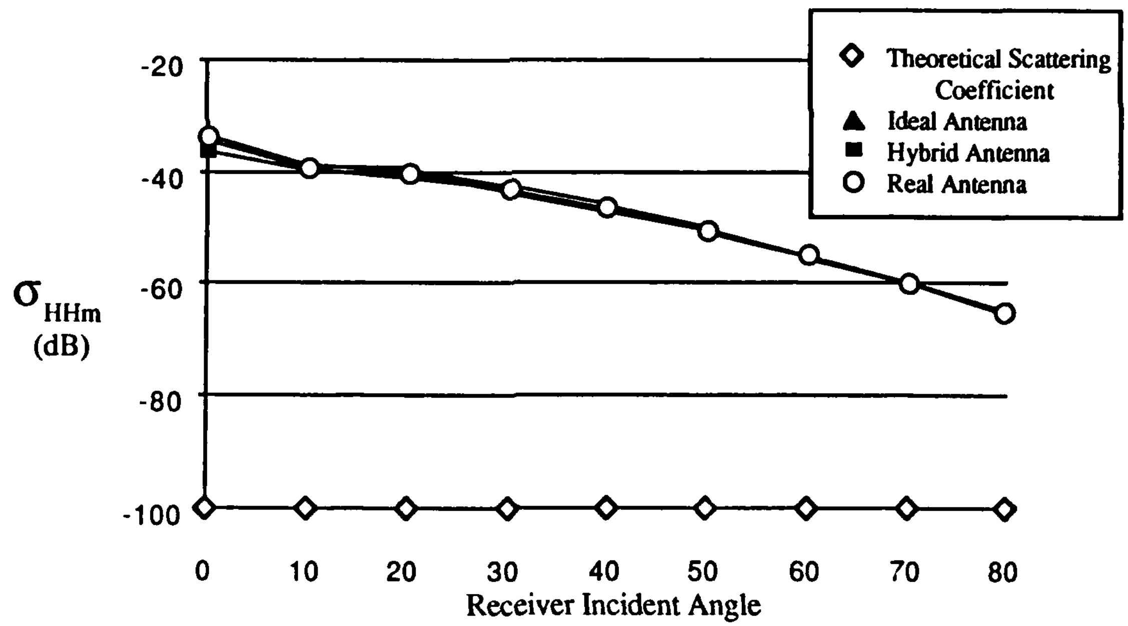

Figure 5-6. Measured Like-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 90°, Transmitter Incidence = 60°.

polarized scattering was received. All antennas showed the same range of value (-35 dB to -65 dB) for all receiver incident angles. The greatest deviation of measured versus expected like-polarized returns occurred at $\Phi_S = 135°$ (figure 5-7). This deviation, however, was limited to between 1 dB and 2 dB except at nadir, where the effect of translation depolarization lowered all antenna responses to 4 dB below the expected value. The forward scatter plot ($\Phi_S = 180°$, figure 5-8) shows perfect antenna response to the expected like-pol scattering response, except at nadir, where translation depolarization has it's greatest effect.

Analysis of the cross polarization measurements shows large deviations from the expected value. At both 0° and 180° azimuth (figures 5-9 and 5-10), no cross polarization scattering is expected, however significantly large cross polarization scattering was measured. Significant measured differences can be seen directly attributable to antenna type. The ideal antenna came closest to the expected cross-pol values. It's worst measurement was at nadir and measurements got progressively better as incident angle increased. The difference in expected and measured results is caused by translation depolarization since the ideal antenna had no cross-pol feedthrough to contribute to antenna effects. The hybrid and real antennas show the added effects of cross polarization feedthrough. The real antenna at the best measurement ($\theta_S = 80°$) was still 60 dB higher than the expected cross-pol scattering coefficient. Close examination of the forward scattering plot ($\Phi_S = 180°$) shows the measured cross-pol return of all antennas rises in a manner similar to the expected like-pol scattering coefficient at these incident angles (figure 5-8). In fact, the real antenna measured the cross-pol coefficient to be almost exactly equal to the theoretical like-pol scattering coefficient for all incident angles at this azimuth. This indicates that the source of the cross-pol measurement is a depolarization phenomena inflicted on the like-pol coefficient. The ideal antenna shows the effects of translation depolarization. The difference between the ideal and real antenna measurement curves

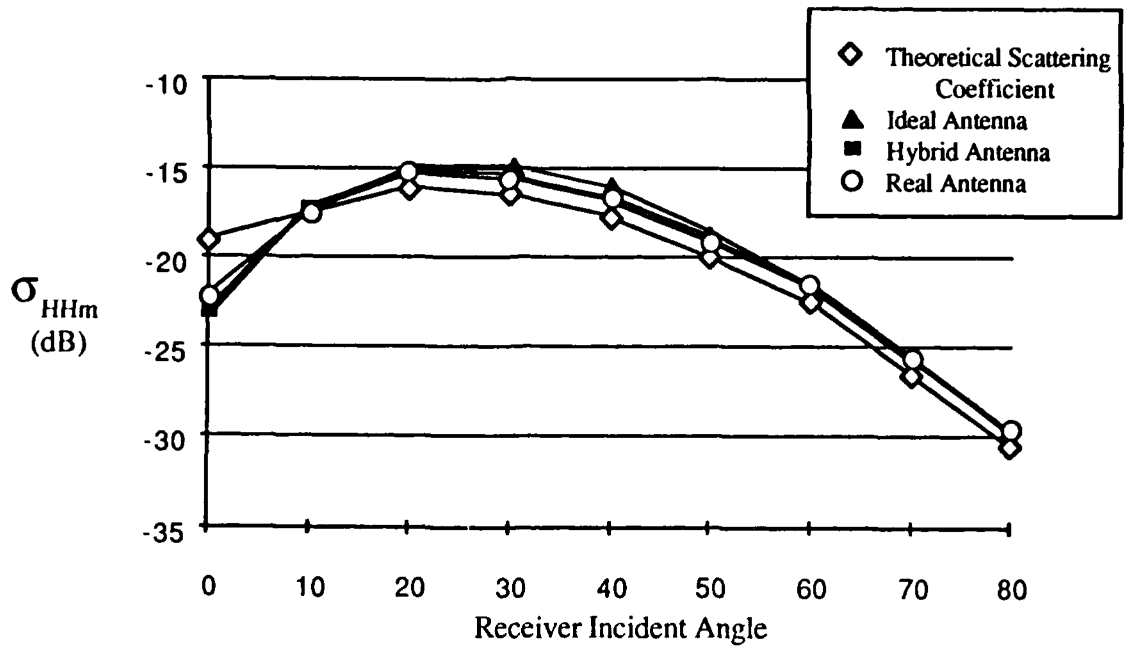

Figure 5-7. Measured Like-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 135°, Transmitter Incidence = 60°.

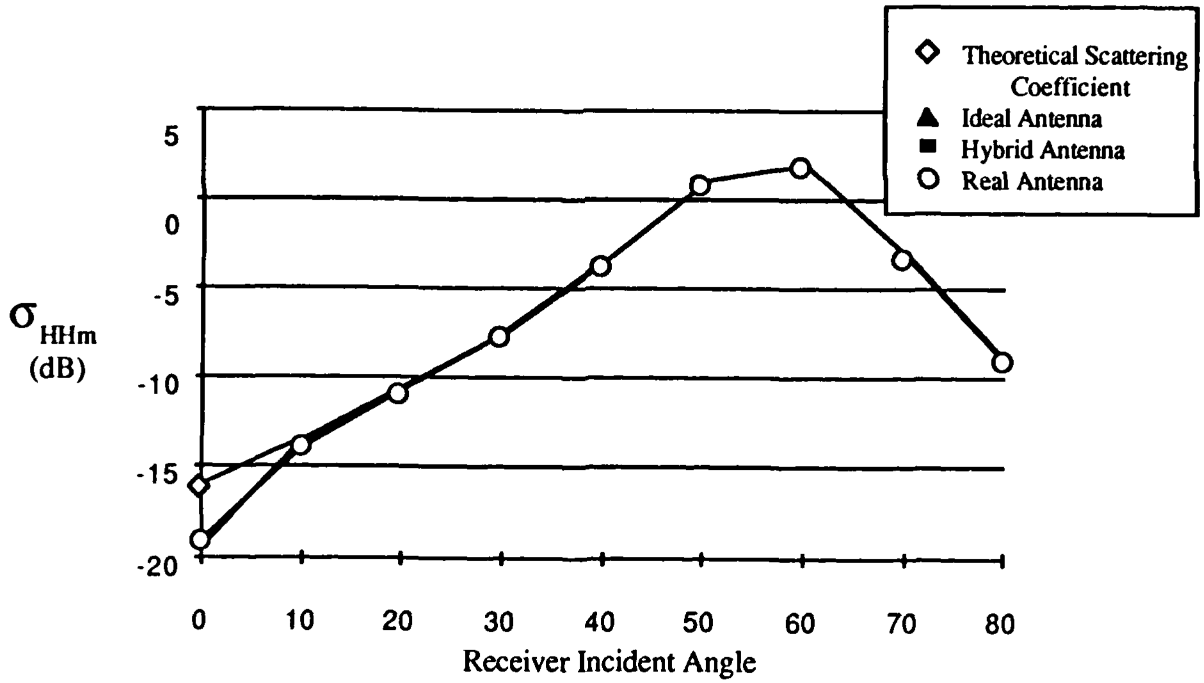

Figure 5-8. Measured Like-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 180°, Transmitter Incidence = 60°.

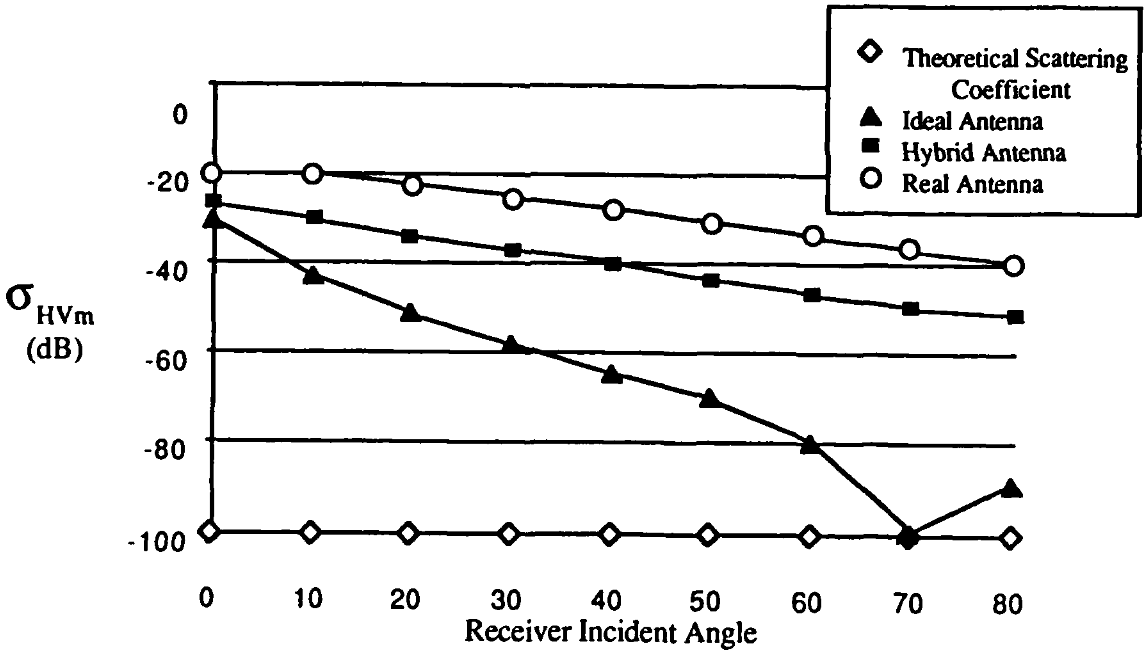

Figure 5-9. Measured Cross-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 0°, Transmitter Incidence = 60°.

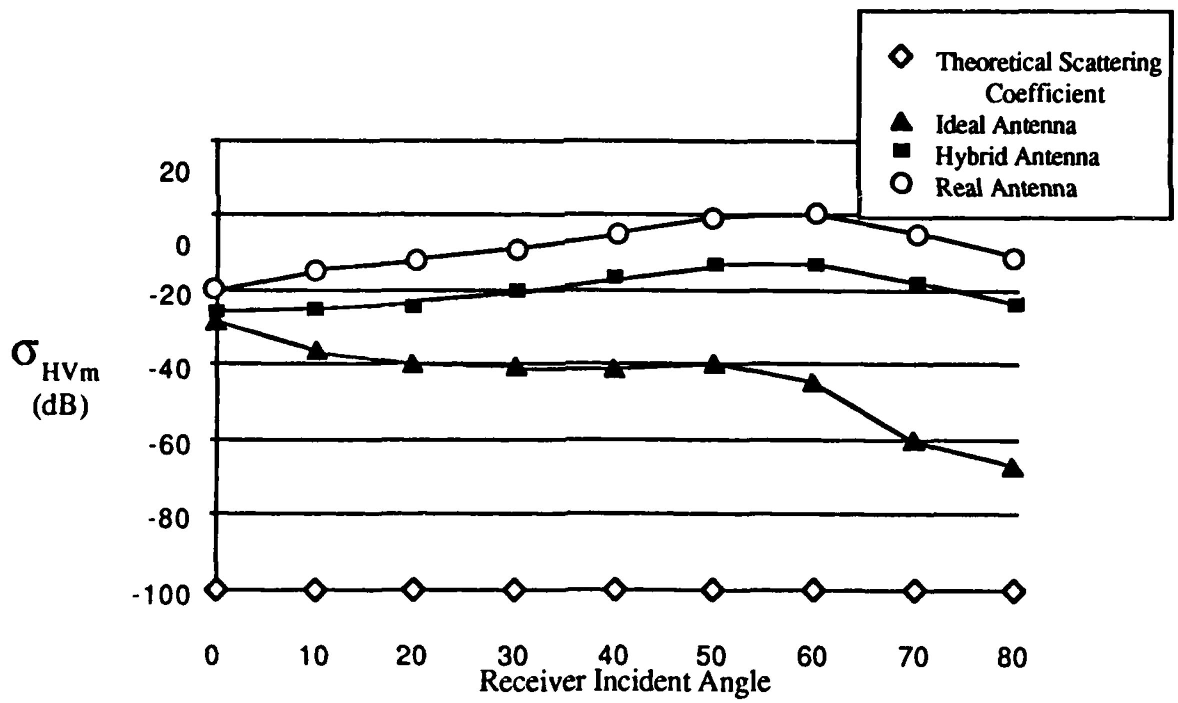

Figure 5-10. Measured Cross-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 180°, Transmitter Incidence = 60°.

shows the added effects of other depolarization phenomena sources. Two sources are immediately apparent. The primary source is antenna depolarization from the imperfect antennas used for transmitting and receiving. Antenna depolarization adds as much as 45 dB to the measurement at the specular scattering angle ($\theta_S = 60°$). The secondary source is additional beamwidth that exists outside the half-power beamwidth in the real antenna. Translation depolarization has a greater effect the further from boresight the antenna pattern occurs. At $\Phi_S = 45°$ and $\Phi_S = 135°$ (figures 5-11 and 5-12, respectively), the ideal antenna measured the cross polarization scattering very accurately except at the 0° incident angle, where Ψ becomes large. The real and hybrid antennas showed significant differences in measuring the cross-polarization scattering depending on their relative cross-polarization response. Once again this difference is attributable to antenna feedthrough of cross polarized signals. The difference between the measured cross-pol scattering coefficient as see by the real antenna and the ideal antenna narrows as the receiver azimuth angle approaches 90°. Only at the 90° azimuth angle (figure 5-13) do all antennas measure the cross polarization scattering accurately.

Significant results were revealed by the theoretical measurement the bistatic scattering coefficients. These were:

(1) While measuring the like-pol scattering coefficient at $\Phi_S = 90°$, significant returns were found where none should have been.

(2) While measuring the cross-pol scattering coefficient, two important results were found. These were:

(a) All antennas measured cross-pol coefficient values much higher than was theoretically expected.

(b) The antennas themselves showed significant variability in the measurement of the cross-pol scattering coefficient.

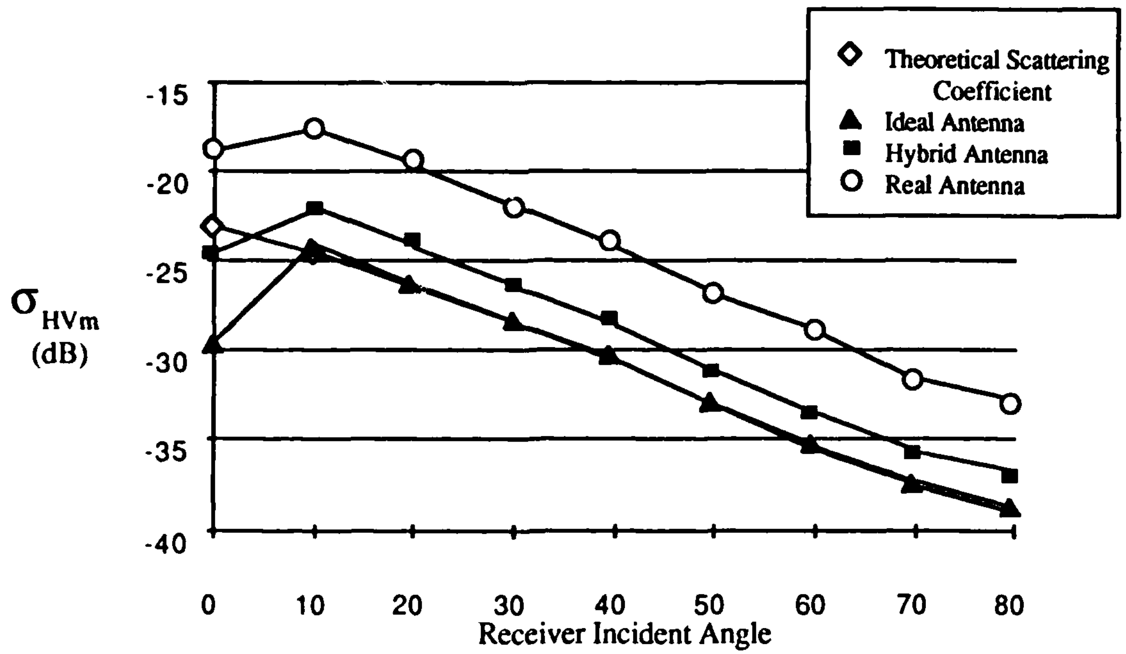

Figure 5-11. Measured Cross-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 45°, Transmitter Incidence = 60°.

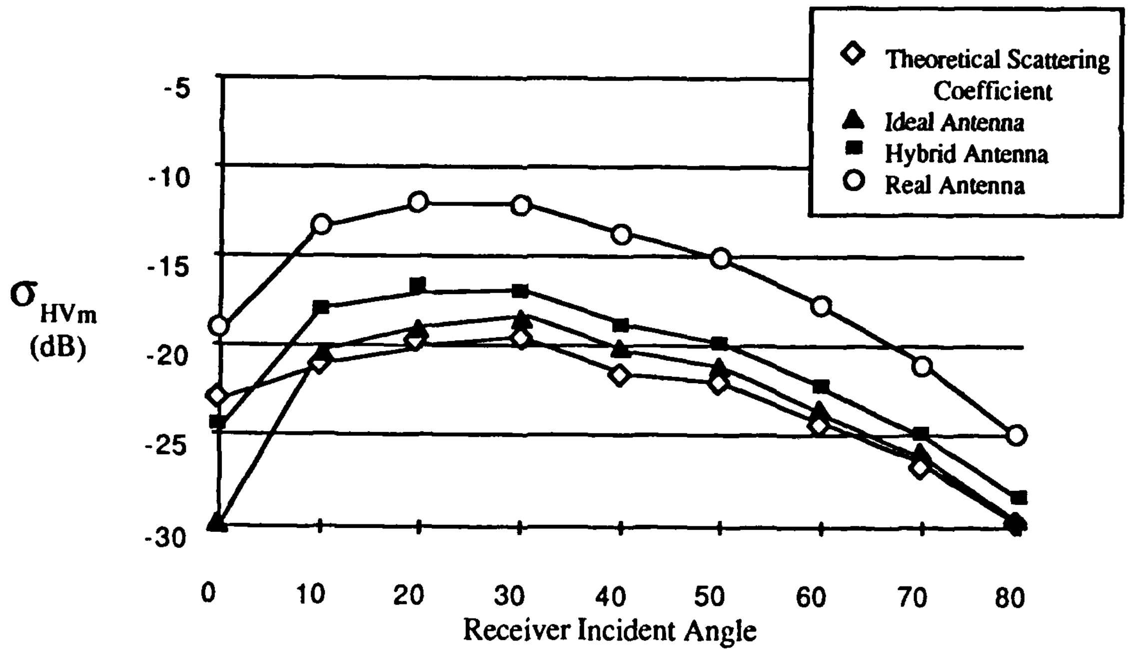

Figure 5-12. Measured Cross-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 135°, Transmitter Incidence = 60°.

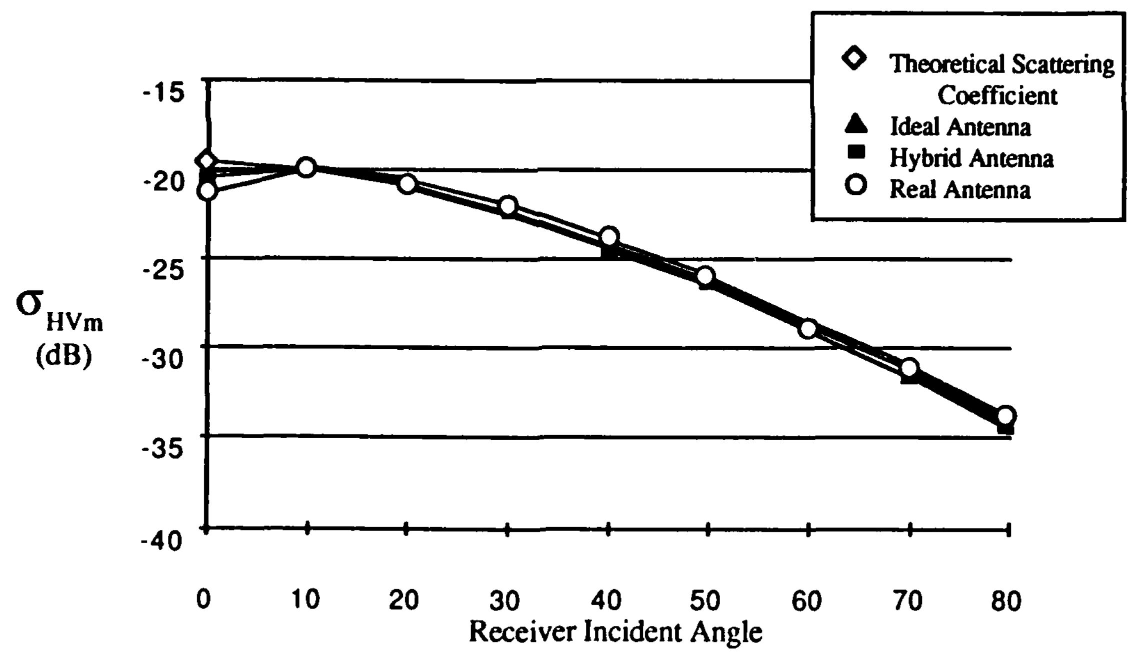

Figure 5-13. Measured Cross-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 90°, Transmitter Incidence = 60°.

CHAPTER SIX

CONCLUSIONS

This chapter discusses the conclusions reached when observing the results of the simulation. Recall, a simulation was designed to model the measurement of bistatic scattering coefficients. The theoretical scattering coefficients used as input to the simulation were themselves theoretical coefficients produced by a simplified Kirchoff scattering model. Significant differences were found in the comparison of the expected results with the simulation results.

Two important conclusions can be drawn from these results. One conclusion can be drawn about translation depolarization and the second concerns antenna feedthrough.

First, the relative orientation of the antenna with the ground, which results in translation depolarization, creates a major depolarization effect at 0° incidence angle when the translation angle, Ψ, becomes large. This effect is nullified when the incident angle is greater than 10°. This effect, at nadir, was seen in all the simulation geometries tested. A further contribution from translation depolarization occurred when measuring cross-pol scattering coefficients with the receiver azimuth plane on the transmitter incident plane (receiver azimuth equals 0° and 180°). No cross-pol scattering was expected in this particular geometry. However, even the ideal antenna, with antenna depolarization nullified, measured significant levels of cross-pol scattering.

The second conclusion that can be drawn from the results, particularly the cross polarization measurements, is that antenna feedthrough effects contribute a large part to the cross-pol scattering measurement made at the receiver in a bistatic environment. This conclusion is demonstrated by the differences in measurement shown between the real and

ideal antennas. The transmitting and receiving antennas, suffering from cross polarization feedthrough effects, deliver and accept extraneous information which can greatly increase the measured value of the cross polarization scattering which is expected off of a given surface.

Clearly, knowledge of translation and antenna depolarization effects and their contributions to scattering coefficient measurements is necessary in order to correctly identify sources of cross polarization scattering measurements in a bistatic environment. Three areas of the measurement system must be controlled in order to minimize measurement of system induced depolarization and maximize measurement of target induced depolarization. These are:

(1) No measurements should be taken at or near nadir. Significant translation depolarization occurs at nadir even when using "ideal" antennas.

(2) Antennas should be chosen to assure the maximum isolation ratio between like and cross polarized channels across the entire beamwidth of the antenna.

(3) Antennas should be chosen with minimum beamwidth in order to nullify translation depolarization effects which occur off-axis.

APPENDIX A

COMPUTER PROGRAMS

```
            PROGRAM DATAINPUT
      C
      C*************************************************************************
      C     THE PURPOSE OF THIS PROGRAM IS TO INPUT THE DATA NEEDED TO         *
      C     CALCULATE THE VALUES OF RADAR BACKSCATTERING COEFFICIENTS.         *
      C     DATA CONCERNING ANTENNA LIKE- AND CROSS-POLARIZATION VALUES,       *
      C     AND TERRAIN CHARACTERISTICS IS PLACED INTO APPROPRIATE FILES.      *
      C     THE PROGRAM IS THEN USED TO MAKE THE DESIRED CALCULATIONS,         *
      C     USING THE DATA INPUT HERE.                                         *
      C*************************************************************************
      C
      C     SET UP SELECTION MENU FOR USER
      C
      10    WRITE(6,700)
      700   FORMAT('1',////,25X,'SYSTEM EFFECTS ANALYSIS',
          1 ///,' 1.  INPUT ANTENNA DATA',
          2   /,' 2.  INPUT RUN SET DATA',
          3   /,' 3.  INPUT ISOTROPIC/MONOSTATIC TERRAIN FILE',
          4   /,' 4.  INPUT BISTATIC TERRAIN FILE',
          5   /,' 5.  END')
      C
            ICHOICE=GETVAR(' ENTER CHOICE - ')
      C
      C     FOR AN INCORRECT CHOICE, RETURN TO SELECTION MENU.
      C
            IF (ICHOICE.LT.1.OR.ICHOICE.GT.5) GOTO 10
            GO TO (50,100,150,200,999) ICHOICE
      C
      50    CALL ANTIN
            GO TO 10
      C
      100   CALL RUNIN
            GO TO 10
      C
      150   CALL MONOTERRAIN
            GO TO 10
      C
      200   CALL BISTATTERRAIN
            GO TO 10
      C
      999   CONTINUE
      C
            END
```

```
      SUBROUTINE ANTIN
C
C**********************************************************************
C     INPUT ANTENNA PATTERN DATA                                      *
C**********************************************************************
C
      DIMENSION LIKE(-50:50,0:50),CROSS(-50:50,0:50)
      REAL LIKE
      CHARACTER*6 ANT
      CHARACTER*10 ANTFILNAM
      LOGICAL AGAIN,YESNO
      COMMON /POINTS/BWINC,MAXPT
C
      WRITE(6,700)
700   FORMAT('1',////,25X,'ANTENNA DATABASE INPUT ROUTINE')
C
C     CALL SUBROUTINE 'GETANTNAM' TO INPUT ANTENNA FILE NAME.
C     IF FILE ALREADY EXISTS, ASK IF IT IS TO BE REPLACED.
C
      CALL GETANTNAM(ANT,ANTFILNAM,STATUS)
      IF (STATUS.EQ.1) THEN
            AGAIN=YESNO(' REPLACE(Y,N)?')
            IF (.NOT.AGAIN) GO TO 999
      ENDIF
C
C     ENTER BEAMWIDTH AND INCREMENTAL RESOLUTION ACROSS BEAMWIDTH
C     VALUES ARE ENTERED IN DEGREES
C
      BW=GETVAR(' ENTER BEAMWIDTH:')
      BWINC=GETVAR(' ENTER INCREMENTAL RESOLUTION ACROSS BEAMWIDTH:')
C
C     DEFINE NUMBER OF DATA POINTS ACROSS BEAMWIDTH
C
      BWPTS=BW/BWINC
      IF((MOD(BWPTS,2.0)).EQ.0) BWPTS=BWPTS+1
      MAXPT=INT(BWPTS/2)+1
C
      WRITE(6,702)
702   FORMAT(/,' *** ENTER LIKE POLARIZATION RESPONSE',
     1        ' ACROSS BEAMWIDTH ***',//)
      CALL GETARRAY(LIKE)
      CALL FILL(LIKE)
C
      WRITE(6,704)
704   FORMAT(/,' *** ENTER CROSS POLARIZATION RESPONSE',
     1        ' ACROSS BEAMWIDTH ***',//)
C
      CALL GETARRAY(CROSS)
      CALL FILL(CROSS)
C
C     PASS DATA TO SUBROUTINE FOR STORAGE
C
      CALL STORANT(ANT,ANTFILNAM,BW,BWINC,MAXPT,LIKE,CROSS)
C
999   CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE RUNIN
C
C**************************************************************************
C     INPUT RUN SET DATA                                                 *
C**************************************************************************
C
      COMMON /LARGE/SIZE,YSIZE,AREA
      CHARACTER*6 TXANT,RXANT,TERNAM
      CHARACTER*8 RUNNAM
      CHARACTER*11 RUNFILNAM
      CHARACTER*10 TXFILNAM,RXFILNAM,TERFILNAM
      CHARACTER*1 MONOSTATIC,RXNOMOMATCH,ANTPOLAR
      INTEGER STATUS,TXVERPOL,TXHORPOL,RXVERPOL,RXHORPOL
C
C     INPUT NAME OF RUN FILE.  CREATE AN INPUT FILE WITH GIVEN NAME
C
      WRITE(6,800)
800   FORMAT('1',////,25X,'RUN SET DATA INPUT ROUTINE')
C
      WRITE(6,700)
700   FORMAT(//,' INPUT NAME OF RUN FILE')
C
      ACCEPT 701,RUNNAM
701   FORMAT(A8)
C
      RUNFILNAM=RUNNAM//'.IN'
C
      SIZE=GETVAR(' ENTER MATRIX SIZE')
      YSIZE=GETVAR(' ENTER X:Y RATIO (1:?)')
C
C     GET TX ANTENNA NAME
C
      WRITE(6,702)
702   FORMAT(/,' *** TRANSMITTER ***',/)
C
      CALL GETANTNAM(TXANT,TXFILNAM,STATUS)
      IF (STATUS.EQ.0) THEN     ! ABORT PROGRAM IF FILE DOESN'T EXIST
            WRITE(6,703)
703         FORMAT(' RUN ABORTED *** TX ANTENNA FILE NOT FOUND')
            GOTO 999
      ENDIF
C
C     GET TX ANTENNA POLARIZATION
C
205   WRITE(6,300)
300   FORMAT(/,' ENTER TRANSMITTER POLARIZATION (V,H)-')
C
      ACCEPT 707,ANTPOLAR
C
      IF (ANTPOLAR.EQ.'V') THEN
            TXVERPOL=1
            TXHORPOL=0
      ELSE
            IF (ANTPOLAR.EQ.'H') THEN
                  TXVERPOL=0
                  TXHORPOL=1
            ELSE
                  GOTO 205
            ENDIF
      ENDIF
```

```
RUNIN
C
C     GET RX ANTENNA NAME
C
      WRITE(6,704)
704   FORMAT(/,' *** RECEIVER ***',/)
C
      CALL GETANTNAM(RXANT,RXFILNAM,STATUS)
      IF (STATUS.EQ.0) THEN              ! ABORT RUN IF FILE DOESN'T EXIST
            WRITE(6,705)
705         FORMAT(' RUN ABORTED *** RX ANTENNA FILE NOT FOUND')
            GOTO 999
      ENDIF
C
C     GET RECEIVER ANTENNA POLARIZATION
C
210   WRITE(6,310)
310   FORMAT(/,' ENTER RECEIVER POLARIZATION (V,H)-')
      ACCEPT 707,ANTPOLAR
C
      IF (ANTPOLAR.EQ.'V') THEN
            RXVERPOL=1
            RXHORPOL=0
      ELSE
            IF (ANTPOLAR.EQ.'H') THEN
                  RXVERPOL=0
                  RXHORPOL=1
            ELSE
                  GOTO 210
            ENDIF
      ENDIF
C
      WRITE(6,706)
706   FORMAT(/,' RECEIVER AND TRANSMITTER IN SAME LOCATION (Y,N)?')
C
      ACCEPT 707,MONOSTATIC
707   FORMAT(A1)
C
C     GET TRANSMITTER POSITION IF TRANSMITTER, RECEIVER ARE NOT IN
C     THE SAME LOCATION
C
      IF (MONOSTATIC.NE.'Y'.AND.MONOSTATIC.NE.'y') THEN
            TXMID=GETVAR(' ENTER GROUND DISTANCE FROM TX TO TARGET')
            TXHEIGHT=GETVAR(' ENTER TRANSMITTER HEIGHT')
      ENDIF
C
      RXSLANT=GETVAR(' ENTER SLANT DISTANCE FROM RX TO TARGET')
      RXNOMTHETAMIN=GETVAR(' ENTER MINIMUM RX INCIDENT ANGLE')
      RXNOMTHETAMAX=GETVAR(' ENTER MAXIMUM RX INCIDENT ANGLE')
C
C     ASK IF RECEIVER ANTENNA INCLINATION MATCHES INCIDENT ANGLE.
C     IF NOT, GET MINIMUM AND MAXIMUM RECEIVER ANTENNA INCLINATIONS.
C
      WRITE(6,708)
708   FORMAT(/,' RX ANTENNA INCLINATION MATCH INCIDENT ANGLE (Y,N)?')
C
      ACCEPT 709,RXNOMOMATCH
709   FORMAT(A1)
```

```
RUNIN
C
      IF (RXNOMOMATCH.NE.'Y'.AND.RXNOMOMATCH.NE.'y') THEN
          RXTHETA0MIN=GETVAR(' ENTER MINIMUM RX ANTENNA INCLINATION')
          RXTHETA0MAX=GETVAR(' ENTER MAXIMUM RX ANTENNA INCLINATION')
      ELSE
          RXTHETA0MIN=RXNOMTHETAMIN
          RXTHETA0MAX=RXNOMTHETAMAX
      ENDIF
C
      RXAZIM=GETVAR(' ENTER RX AZIMUTH ANGLE')
C
C     GET DESIRED TERRAIN FILE.  ABORT RUN IF FILE DOESN'T EXIST
C
      CALL GETTERNAM(TERNAM,TERFILNAM,STATUS)
      IF (STATUS.EQ.O) THEN
              WRITE(6,715)
715           FORMAT(' RUN ABORTED *** TERRAIN FILE NOT FOUND')
              GOTO 999
      ENDIF
C
C     OPEN RUN FILE AND ENTER INPUT DATA
C
      OPEN(UNIT=20,FILE=RUNFILNAM,STATUS='NEW',RECORDSIZE=1000)
C
      WRITE(20,200)MONOSTATIC,RXNOMOMATCH,TXANT,RXANT,
     1        TXMID,TXHEIGHT,
     2        RXSLANT,RXNOMTHETAMIN,RXNOMTHETAMAX,
     3        RXTHETA0MIN,RXTHETA0MAX,
     4        RXAZIM,SIZE,YSIZE,TERNAM,
     5        TXVERPOL,TXHORPOL,RXVERPOL,RXHORPOL
200   FORMAT(2A1,2A6,10F14.7,A6,4I1)
C
      CLOSE(UNIT=20)
C
C     CREATE COMMAND FILE WITH RUN FILE NAME TO RUN PROGRAM 'SYSEFF'
C
      OPEN(UNIT=20,FILE=RUNNAM//'.COM',STATUS='NEW')
      WRITE(20,201)RUNNAM
201   FORMAT('$ RUN SYSEFF',/,A8)
      CLOSE(UNIT=20)
C
999   RETURN
      END
```

```
      SUBROUTINE MONOTERRAIN
C
C*****************************************************************************
C     INPUT MONOSTATIC TERRAIN DATA                                          *
C*****************************************************************************
C
      CHARACTER*6 TER
      CHARACTER*10 TERFILNAM
      LOGICAL AGAIN,YESNO
C
      WRITE(6,700)
700   FORMAT('1',////,25X,
     1        'MONOSTATIC TERRAIN DATA FILE INPUT ROUTINE')
C
C     GET A SIX-CHARACTER TERRAIN FILE IDENTIFIER.  ASK IF ANY
C     EXISTING VERSION OF THE FILE SHOULD BY REPLACED.
C
      CALL GETTERNAM(TER,TERFILNAM,STATUS)
      IF (STATUS.EQ.1) THEN
              AGAIN=YESNO(' REPLACE(Y,N)?')
              IF (.NOT.AGAIN) GO TO 999
      ENDIF
C
C     GET SCATTERING COEFFICIENTS
C
      SIGVV=GETVAR(' ENTER VV SCATTERING COEFFICIENT (IN DB)')
      ANGVV=GETVAR(' ENTER VV PHASE ANGLE')
      SIGVH=GETVAR(' ENTER VH SCATTERING COEFFICIENT (IN DB)')
      ANGVH=GETVAR(' ENTER VH PHASE ANGLE')
      SIGHV=GETVAR(' ENTER HV SCATTERING COEFFICIENT (IN DB)')
      ANGHV=GETVAR(' ENTER HV PHASE ANGLE')
      SIGHH=GETVAR(' ENTER HH SCATTERING COEFFICIENT (IN DB)')
      ANGHH=GETVAR(' ENTER HH PHASE ANGLE')
C
C     OPEN DATA STORAGE FILE
C
      OPEN (UNIT=20,FILE=TERFILNAM,STATUS='NEW',RECORDSIZE=500)
C
      WRITE (20,200)SIGVV,SIGVH,SIGHV,SIGHH,ANGVV,ANGVH,ANGHV,ANGHH
200   FORMAT (8F14.7)
C
      CLOSE (UNIT=20)
C
999   CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE BISTATTERRAIN
C***********************************************************************
C     INPUT BISTATIC TERRAIN DATA                                      *
C***********************************************************************
      DIMENSION SIGVV(0:8),SIGVH(0:8),SIGHV(0:8),SIGHH(0:8)
      DIMENSION ANGVV(0:8),ANGVH(0:8),ANGHV(0:8),ANGHH(0:8)
      CHARACTER*6 TER
      CHARACTER*10 TERFILNAM
      LOGICAL AGAIN,YESNO
C
      WRITE(6,700)
700   FORMAT('1',////,25X,'BISTATIC TERRAIN DATA FILE INPUT ROUTINE')
C
C     GET A SIX-CHARACTER TERRAIN FILE IDENTIFIER.  ASK IF ANY
C     EXISTING VERSION OF THE FILE SHOULD BE REPLACED.
C
      CALL GETTERNAM(TER,TERFILNAM,STATUS)
      IF (STATUS.EQ.1) THEN
              AGAIN=YESNO(' REPLACE(Y,N)?')
              IF (.NOT.AGAIN) GO TO 999
      ENDIF
C
C     ENTER RECEIVER AZIMUTH ANGLE, TRANSMITTER INCIDENT ANGLE
C
      AZIM=GETVAR(' ENTER RX AZIMUTH ANGLE')
      TXINC=GETVAR(' ENTER TX INCIDENT ANGLE')
C
C     FOR INCIDENT ANGLES PHI = 0 TO 80 DEGREES, GET SCATTERING
C     COEFFICIENTS AND PHASE ANGLES
C
      DO 50 I=0,8
      PHI=10*I
      WRITE(6,701) PHI
701   FORMAT(' INCIDENT ANGLE=',F5.2)
C
      SIGVV(I)=GETVAR(' ENTER VV SCATTERING COEFFICIENT (IN DB)')
      ANGVV(I)=GETVAR(' ENTER VV PHASE ANGLE')
      SIGVH(I)=GETVAR(' ENTER VH SCATTERING COEFFICIENT (IN DB)')
      ANGVH(I)=GETVAR(' ENTER VH PHASE ANGLE')
      SIGHV(I)=GETVAR(' ENTER HV SCATTERING COEFFICIENT (IN DB)')
      ANGHV(I)=GETVAR(' ENTER HV PHASE ANGLE')
      SIGHH(I)=GETVAR(' ENTER HH SCATTERING COEFFICIENT (IN DB)')
      ANGHH(I)=GETVAR(' ENTER HH PHASE ANGLE')
C
50    CONTINUE
C
C     OPEN TERRAIN DATA STORAGE FILE
C
      OPEN (UNIT=20,FILE=TERFILNAM,STATUS='NEW',RECORDSIZE=500)
      WRITE (20,199) AZIM,TXINC
199   FORMAT (2F8.3)
C
      DO 60 I=0,8
60    WRITE (20,200)SIGVV(I),SIGVH(I),SIGHV(I),SIGHH(I),
     1              ANGVV(I),ANGVH(I),ANGHV(I),ANGHH(I)
200   FORMAT (8F14.7)
      CLOSE (UNIT=20)
999   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE GETANTNAM(ANT,ANTFILNAM,STATUS)
C
C*************************************************************************
C     INPUT ANTENNA IDENTIFIER                                           *
C*************************************************************************
C
      CHARACTER*6 ANT
      CHARACTER*10 ANTFILNAM
C
C     GET SIX-CHARACTER NAME FOR ANTENNA FILE
C
      WRITE(6,700)
700   FORMAT(' ENTER ANTENNA IDENTIFIER:')
C
      ACCEPT 701,ANT
701   FORMAT(A6)
C
      ANTFILNAM=ANT//'.ANT'
C
C     OPEN FILE WITH GIVEN NAME; INDICATE IF FILE ALREADY EXISTS
C
      OPEN(UNIT=10,FILE=ANTFILNAM,STATUS='OLD',ERR=10)
      CLOSE(UNIT=10)
C
      WRITE(6,702)
702   FORMAT(' FILE FOUND')
      STATUS=1
      GOTO 99
C
10    WRITE(6,703)
703   FORMAT(' FILE NOT FOUND')
C
      STATUS=0
C
99    RETURN
      END
```

```
            SUBROUTINE GETTERNAM(TER,TERFILNAM,STATUS)
C
C**************************************************************************
C           INPUT TERRAIN IDENTIFIER                                     *
C**************************************************************************
C
            CHARACTER*6 TER
            CHARACTER*10 TERFILNAM
C
C           GET SIX-CHARACTER TERRAIN FILE NAME
C
            WRITE(6,700)
700         FORMAT(/,' ENTER TERRAIN FILE IDENTIFIER:')
C
            ACCEPT 701,TER
701         FORMAT(A6)
C
            TERFILNAM=TER//'.TER'
C
C           OPEN FILE WITH GIVEN NAME; INDICATE IF FILE ALREADY EXISTS
C
            OPEN(UNIT=10,FILE=TERFILNAM,STATUS='OLD',ERR=10)
            CLOSE(UNIT=10)
C
            WRITE(6,702)
702         FORMAT(' FILE FOUND')
            STATUS=1
            GOTO 99
C
10          WRITE(6,703)
703         FORMAT(' FILE NOT FOUND')
            STATUS=0
C
99          RETURN
            END
```

```
      SUBROUTINE GETARRAY(MAT)
C
C*****************************************************************************
C     INPUT ARBITRARY ARRAY OF ANTENNA PATTERN DATA                          *
C*****************************************************************************
C
      REAL MAT(-50:50,0:50)
      COMMON /POINTS/BWINC,MAXPT
C
C     INPUT ONE-WAY POWER PATTERN VALUES (IN DB) FOR EACH
C     INCREMENTAL ANGLE
C
      DO 10 I=0,MAXPT-1
      PHI=BWINC*I
      WRITE(6,700) PHI
700   FORMAT(' ANGLE=',F5.2,'  DB=')
      READ(5,*) MAT(0,I)
C
C     CONVERT FROM DB
C
      MAT(0,I)=10**(MAT(0,I)/20)
C
10    CONTINUE
C
      RETURN
      END


      SUBROUTINE FILL(MAT)
C
C*****************************************************************************
C     FILL ANTENNA PATTERN MATRIX WITH VALUES BASED UPON INPUT VECTOR
C*****************************************************************************
C
      REAL MAT(-50:50,0:50),MAXDIS,PNTDIS
      COMMON /POINTS/BWINC,MAXPT
C
      MAXDIS=DIST(0,MAXPT-1)
C
      DO 10 I=1,MAXPT-1
      DO 10 J=0,MAXPT-1
      PNTDIS=DIST(I,J)
C
C     INTERPOLATE BETWEEN KNOWN INPUT POINTS
C
      IF(PNTDIS.GT.MAXDIS) THEN
            MAT(I,J)=0
      ELSE
            II=ABS(INT(PNTDIS))
            FRAC=PNTDIS-II
            DIFF=MAT(0,II+1)-MAT(0,II)
            MAT(I,J)=MAT(0,II)+FRAC*DIFF
      ENDIF
C
      MAT(-I,J)=MAT(I,J)
C
10    CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE GETANT(ANT,NAM,BW,BWINC,MAXPT,VERT,CROSS)
C
C**************************************************************************
C     READS ANTENNA DATA FROM FILE                                        *
C**************************************************************************
C
      DIMENSION LIKE(-50:50,0:50),CROSS(-50:50,0:50)
      REAL LIKE
      CHARACTER*6 ANT
      CHARACTER*10 NAM
C
C     OPEN A FILE WITH ANTENNA IDENTIFIER NAME
C
      OPEN (UNIT=10,FILE=NAM,STATUS='OLD')
C
      READ(10,700) ANT,BW,BWINC,MAXPT
700   FORMAT(A6,2F8.3,I4)
C
      DO 10 I=-(MAXPT-1),MAXPT-1
10    READ(10,701)(LIKE(I,J),J=0,MAXPT-1)
      DO 20 I=-(MAXPT-1),MAXPT-1
20    READ(10,701)(CROSS(I,J),J=0,MAXPT-1)
701   FORMAT(100F8.3)
C
      CLOSE(UNIT=10)
C
      RETURN
      END
```

```
      SUBROUTINE STORANT(ANT,NAM,BW,BWINC,MAXPT,LIKE,CROSS)
C
C****************************************************************************
C     STORES ANTENNA DATA INTO FILE                                         *
C****************************************************************************
C
      DIMENSION LIKE(-50:50,0:50),CROSS(-50:50,0:50)
      REAL LIKE
      CHARACTER*6 ANT
      CHARACTER*10 NAM
C
      OPEN (UNIT=10,FILE=NAM,STATUS='NEW',RECL=10000)
C
      WRITE (10,700) ANT,BW,BWINC,MAXPT
700   FORMAT(A6,2F8.3,I4)
C
      DO 10 I=-(MAXPT-1),MAXPT-1
10    WRITE (10,701) ((LIKE(I,J),J=0,MAXPT-1))
      DO 20 I=-(MAXPT-1),MAXPT-1
20    WRITE (10,701) ((CROSS(I,J),J=0,MAXPT-1))
701   FORMAT((100F8.3))
C
      CLOSE(UNIT=10)
C
      RETURN
      END
```

```
      FUNCTION DIST(X,Y)
C
C*****************************************************************************
C      COMPUTE DISTANCE FROM CENTER TO ARBITRARY MATRIX CELL                  *
C*****************************************************************************
C
      INTEGER X,Y
      DIST=(((X)**2+(Y)**2)**0.5)
      RETURN
      END
```

```
      FUNCTION GETVAR(QUERY)
C
C*****************************************************************************
C      RETRIEVE ANSWER FROM USER                                              *
C*****************************************************************************
C
      CHARACTER*(*) QUERY
C
      WRITE(6,700)
700   FORMAT(X)
C
      WRITE(6,*) QUERY
      READ(5,*) GETVAR
C
      RETURN
      END
```

```
      LOGICAL FUNCTION YESNO(QUERY)
C
C*****************************************************************************
C      THIS FUNCTION RETURNS TRUE OR FALSE TO A YES/NO QUESTION               *
C*****************************************************************************
C
      CHARACTER*(*) QUERY
      CHARACTER*1 INPUT
C
      WRITE(6,700)
700   FORMAT(X)
C
      WRITE(6,*) QUERY
      READ(5,701) INPUT
701   FORMAT(A1)
C
      IF(INPUT.EQ.'Y') YESNO=.TRUE.
      IF(INPUT.EQ.'y') YESNO=.TRUE.
C
      RETURN
      END
$
```

```
      PROGRAM SYSEFF
C
C***********************************************************************
C                                                                      *
C                                                                      *
C                                                                      *
C     RECEIVER:                                                        *
C       RXDIST - RX ANTENNA GROUND DISTANCE TO TARGET GROUND           *
C       RXAZIM - RX AZIMUTH ANGLE                                      *
C                                                                      *
C     TRANSMITTER:                                                     *
C       TXMAXRANGE - GROUND DISTANCE FROM FRONT OF MATRIX TO REAR      *
C       TXMID    - GROUND DISTANCE FROM BEGINNING OF MATRIX TO TARGET*
C                                                                      *
C     BOTH:                                                            *
C                                                                      *
C       SIZE:              NUMBER OF MATRIX CELLS IN GROUND MATRIX     *
C       YSIZE:             RELATIVE SIZE OF GROUND CELL IN DIRECTION   *
C                          ORTHOGONAL TO BEAM                          *
C       TX(RX)ANT:         ANTENNA NAME                                *
C       TX(RX)THETA0:      ANTENNA INCLINATION ANGLE                   *
C       TX(RX)NOMTHETA:    BEAM INCIDENT ANGLE                         *
C       TX(RX)HEIGHT:      ANTENNA HEIGHT                              *
C       TX(RX)NOMRANGE:    ANTENNA TO TARGET SLANT RANGE               *
C       TX(RX)LOC:         ANTENNA GROUND DISTANCE TO FRONT OF MATRIX  *
C       TX(RX)BW:          ANTENNA BEAMWIDTH                           *
C       TX(RX)BWINC:       ANTENNA INCREMENT ANGLE                     *
C       TX(RX)MAXPT:       NUMBER OF DATA POINTS ACROSS BEAM           *
C       TX(RX)LIKE:        LIKE POLARIZATION PATTERN ACROSS BEAM       *
C       TX(RX)CROSS:       CROSS POLARIZATION PATTERN                  *
C       TX(RX)VERPOL:      VERTICAL POLARIZATION FLAG                  *
C       TX(RX)HORPOL:      HORIZONTAL POLARIZATION FLAG                *
C                                                                      *
C***********************************************************************
C
      COMMON /LARGE/SIZE,YSIZE,AREA
      COMMON /TX/TXANT,TXTHETA0,TXNOMTHETA,TXHEIGHT,TXNOMRANGE,
     1           TXMAXRANGE,TXMID,TXLOC,TXBW,TXBWINC,TXMAXPT,
     2           TXLIKE,TXCROSS,TXVERPOL,TXHORPOL
      COMMON /RX/RXANT,RXTHETA0,RXNOMTHETA,RXHEIGHT,RXNOMRANGE,
     1           RXLOC,RXAZIM,RXBW,RXBWINC,RXMAXPT,
     2           RXLIKE,RXCROSS,RXVERPOL,RXHORPOL
      COMMON /TERRAIN/SIGVV,SIGVH,SIGHV,SIGHH,ANGVV,ANGVH,ANGHV,ANGHH
C
      DIMENSION TXLIKE(-50:50,0:50),TXCROSS(-50:50,0:50)
      DIMENSION RXLIKE(-50:50,0:50),RXCROSS(-50:50,0:50)
      REAL SCATVV(0:8),SCATVH(0:8),SCATHV(0:8),SCATHH(0:8)
      REAL PHASVV(0:8),PHASVH(0:8),PHASHV(0:8),PHASHH(0:8)
      CHARACTER*6 TXANT,RXANT,TERNAM
      CHARACTER*8 RUNNAM
      CHARACTER*11 RUNFILNAM
      CHARACTER*10 TXFILNAM,RXFILNAM
      CHARACTER*1 MONOSTATIC,RXNOMOMATCH
      INTEGER TXVERPOL,TXHORPOL,RXVERPOL,RXHORPOL
      LOGICAL PRINT
C
C     RESET PRINT FLAG FOR OUTPUT TITLES
C
      PRINT=.FALSE.
C
```

```
SYSEFF
                READ(5,702)RUNNAM
      702       FORMAT(A8)
      C
      C         GET DATA FROM RUN SET FILE
      C
                OPEN(UNIT=20,FILE=RUNNAM//'.IN',STATUS='OLD')
                READ(20,200)MONOSTATIC,RXNOMOMATCH,TXANT,RXANT,
           1          TXMID,TXHEIGHT,
           2          RXSLANT,RXNOMTHETAMIN,RXNOMTHETAMAX,
           3          RXTHETAOMIN,RXTHETAOMAX,
           4          RXAZIM,
           5          SIZE,YSIZE,TERNAM,
           6          TXVERPOL,TXHORPOL,RXVERPOL,RXHORPOL
      200       FORMAT(2A1,2A6,10F14.7,A6,4I1)
      C
                CLOSE(UNIT=20)
      C
      C         GET TERRAIN FILE
      C
                OPEN (UNIT=20,FILE=TERNAM//'.TER',STATUS='OLD')
      C
      C         OPEN OUTPUT FILE
      C
                OPEN (UNIT=30,FILE=RUNNAM//'.OUT',STATUS='NEW')
      C
      C         IF SYSTEM GEOMETRY IS MONOSTATIC
      C            GET ISOTROPIC SCATTERING COEFFICIENTS, PHASE ANGLES
      C
                IF (MONOSTATIC.EQ.'Y'.OR.MONOSTATIC.EQ.'y') THEN
      C
                      READ (20,201) SIGVV,SIGVH,SIGHV,SIGHH,
           1                        ANGVV,ANGVH,ANGHV,ANGHH
      201             FORMAT (8F14.7)
      C
      C               OUTPUT TERRAIN CHARACTERISTICS
      C
                      WRITE (30,300) SIGVV,ANGVV,SIGVH,ANGVH,
           1                        SIGHV,ANGHV,SIGHH,ANGHH
      300             FORMAT ('1',' TERRAIN CHARACTERISTICS',//,
           1          ' VV - SCATTERING COEFFICIENT = ',F8.3,
           2          '    PHASE= ',F8.3,/,
           3          ' VH - SCATTERING COEFFICIENT = ',F8.3,
           4          '    PHASE= ',F8.3,/,
           5          ' HV - SCATTERING COEFFICIENT = ',F8.3,
           6          '    PHASE= ',F8.3,/,
           7          ' HH - SCATTERING COEFFICIENT = ',F8.3,
           8          '    PHASE= ',F8.3)
      C
      C               CONVERT SCATTERING CHARACTERISTICS FROM DB
      C
                      SIGVV=10**(SIGVV/10)
                      SIGVH=10**(SIGVH/10)
                      SIGHV=10**(SIGHV/10)
                      SIGHH=10**(SIGHH/10)
```

SYSEFF

```
C
C       GET DATA FOR BISTATIC CASE
C
        ELSE
C
                READ (20,202) AZIM,TXINC
202             FORMAT (2F8.3)
C
C               GET SCATTERING COEFFICIENTS, PHASE ANGLES
C
                DO 150 I=0,3
150             READ (20,203) SCATVV(I),SCATVH(I),SCATHV(I),SCATHH(I),
     1                        PHASVV(I),PHASVH(I),PHASHV(I),PHASHH(I)
203             FORMAT (8F14.7)
C
C               OUTPUT BISTATIC TERRAIN CHARACTERISTICS
C
                WRITE (30,304)
304             FORMAT ('1',' TERRAIN CHARACTERISTICS',//,
     1          ' BISTATIC TERRAIN - VARIES WITH INCIDENT ANGLE')
C
        ENDIF
C
        CLOSE (UNIT=20)
C
C       RETRIEVE TX ANTENNA INFO
C
10      TXFILNAM=TXANT//'.ANT'
        CALL GETANT(TXANT,TXFILNAM,TXBW,TXBWINC,TXMAXPT,TXLIKE,TXCROSS)
C
C       RETRIEVE RX ANTENNA INFO
C
        RXFILNAM=RXANT//'.ANT'
        CALL GETANT(RXANT,RXFILNAM,RXBW,RXBWINC,RXMAXPT,RXLIKE,RXCROSS)
C
C       BEGIN CYCLING THROUGH POINTS TO BE CALCULATED
C       START WITH RX ANTENNA INCLINATION
C
        DO 90 RXTHETA0=RXTHETA0MIN,RXTHETA0MAX,10
C
C       TELL THE OUTSIDE WORLD WHERE YOU ARE
C
        OPEN (UNIT=50,FILE=RUNNAM//'.PRG',STATUS='NEW')
        WRITE (50,500)RXAZIM,RXTHETA0
500     FORMAT (' JUST STARTED AZIMUTH = ',F10.3,' RXTHETA = ',F10.3)
        CLOSE (UNIT=50)
C
C       CHECK IF THETA0 AND NOMINAL THETA ARE TO BE THE SAME
C
        IF (RXNOMOMATCH.EQ.'Y'.OR.RXNOMOMATCH.EQ.'y') THEN
                RXNOMTHETA=RXTHETA0
                GOTO 50
        ENDIF
```

```
SYSLIT
C
C                  CYCLE THROUGH BEAM INCIDENT ANGLES
C
                   DO 90 RXNOMTHETA=RXNOMTHETAMIN,RXNOMTHETAMAX,10
C
C          CALCULATE RX VERTICAL, HORIZONTAL DISTANCES FROM TARGET
C
90         RXNOMRANGE=RXSLANT
           RXHEIGHT=RXNOMRANGE*COSD(RXNOMTHETA)
           RXDIST=RXNOMRANGE*SIND(RXNOMTHETA)
C
C          CHECK TO SEE IF TX AND RX ARE IN SAME LOCATION
C          IF SO, SET TX LOCATION EQUAL TO RX LOCATION
C
           IF (MONOSTATIC.EQ.'Y'.OR.MONOSTATIC.EQ.'y') THEN
                   TXTHETA0=RXTHETA0
                   TXNOMTHETA=RXNOMTHETA
                   TXNOMRANGE=RXNOMRANGE
                   TXMID=TXNOMRANGE
                   TXMAXRANGE=2*TXMID
                   TXHEIGHT=RXHEIGHT
                   RXLOC=TXMID-RXDIST
                   TXLOC=RXLOC
           ELSE
                   TXMAXRANGE=2*TXMID
                   TXNOMTHETA=ATAND(TXMID/TXHEIGHT)
                   TXTHETA0=TXNOMTHETA
                   TXNOMRANGE=TXHEIGHT/COSD(TXNOMTHETA)
                   TXLOC=0.0
                   RXLOC=TXMID-RXDIST
C
C                  GET BISTATIC TERRAIN AT THIS INCIDENT ANGLE
C
                   SIGVV=10**(SCATVV(RXNOMTHETA/10)/10)
                   ANGVV=PHASVV(RXNOMTHETA/10)
                   SIGVH=10**(SCATVH(RXNOMTHETA/10)/10)
                   ANGVH=PHASVH(RXNOMTHETA/10)
                   SIGHV=10**(SCATHV(RXNOMTHETA/10)/10)
                   ANGHV=PHASHV(RXNOMTHETA/10)
                   SIGHH=10**(SCATHH(RXNOMTHETA/10)/10)
                   ANGHH=PHASHH(RXNOMTHETA/10)
           ENDIF
C
80         IF(.NOT.PRINT) THEN
C
C                  OUTPUT TRANSMITTER INFO
C
                   WRITE(30,301)TXANT,TXVERPOL,TXHORPOL,TXNOMRANGE
301                FORMAT(///,' TRANSMITTER DATA',//,
     1             ' ANTENNA TYPE                         >',6X,A6,/,
     2             ' ANTENNA VERTICAL POLARIZATION        >',11X,I1,/,
     3             ' ANTENNA HORIZONTAL POLARIZATION      >',11X,I1,/,
     4             ' ANTENNA->TARGET RANGE                >',F12.3,/)
```

```
SYSEFF
C
C                 OUTPUT RECEIVER INFORMATION
C
                  WRITE(30,302)RXANT,RXVERPOL,RXHORPOL,RXNOMRANGE
  302             FORMAT(///,' RECEIVER DATA',//,
     1            ' ANTENNA TYPE                         >',6X,A6,/,
     2            ' ANTENNA VERTICAL POLARIZATION        >',11X,I1,/,
     3            ' ANTENNA HORIZONTAL POLARIZATION      >',11X,I1,/,
     4            ' ANTENNA->TARGET RANGE                >',F12.3,/)
C
C                 OUTPUT DATA HEADER
C
                  WRITE(30,303)
  303       FORMAT('1',2X,'TRANSMITTER',17X,'RECEIVER',27X,'POWER RETURN',/,
     1           1X,14('+'),10X,22('+'),10X,37('+'),/,
     2           ' INCLIN',3X,'INCID',10X,'  AZ',3X,'INCLIN',3X,'INCID',10X,
     3           '   VV',8X,'VH',8X,'HV',8X,'HH')
C
                  PRINT=.TRUE.
            ENDIF
C
   90       CALL RUNONE
C
            CLOSE (UNIT=30)
            CLOSE (UNIT=90)
C
            END
```

```
      SUBROUTINE RUNONE
C
C***********************************************************************
C     THIS SUBROUTINE RUNS ONE SNAPSHOT OF THE DEPOLARIZATION         *
C     EFFECTS FOR A PARTICULAR RX AZIMUTH AND INCIDENCE ANGLE         *
C                                                                     *
C                                                                     *
C     LIST OF VARIABLES:                                              *
C                                                                     *
C          TX(RX)GROUND:      (1) GROUND MATRIX HOLDING LIKE          *
C                                 POLARIZATION ANTENNA PATTERN        *
C                             (2) GROUND MATRIX HOLDING CROSS         *
C                                 POLARIZATION ANTENNA PATTERN        *
C          TX(RX)THETATAB:        THETA ANGLE OF BEAM ON CELL         *
C          TX(RX)PHITAB:          PHI ANGLE OF BEAM ON CELL           *
C          TX(RX)THETAPTAB:       THETA PRIME ANGLE OF BEAM ON CELL   *
C          TX(RX)PHIPTAB:         PHI PRIME ANGLE OF BEAM ON CELL     *
C          TX(RX)POLAR:       (1) COSINE (PSI) OF BEAM ON CELL        *
C                             (2) SINE (PSI) OF BEAM ON CELL          *
C                                                                     *
C***********************************************************************
C
      COMMON /LARGE/SIZE,YSIZE,AREA
      COMMON /TX/TXANT,TXTHETA0,TXNOMTHETA,TXHEIGHT,TXNOMRANGE,
     1          TXMAXRANGE,TXMID,TXLOC,TXBW,TXBWINC,TXMAXPT,
     2          TXLIKE,TXCROSS,TXVERPOL,TXHORPOL
      COMMON /RX/RXANT,RXTHETA0,RXNOMTHETA,RXHEIGHT,RXNOMRANGE,
     1          RXLOC,RXAZIM,RXBW,RXBWINC,RXMAXPT,
     2          RXLIKE,RXCROSS,RXVERPOL,RXHORPOL
      COMMON /TERRAIN/SIGVV,SIGVH,SIGHV,SIGHH,ANGVV,ANGVH,ANGHV,ANGHH
C
      CHARACTER*6 TXANT,RXANT,RUNNAM
      DIMENSION TXLIKE(-50:50,0:50),TXCROSS(-50:50,0:50)
      DIMENSION RXLIKE(-50:50,0:50),RXCROSS(-50:50,0:50)
      DIMENSION TXGROUND(200,-200:200,2),RXGROUND(200,-200:200,2)
      DIMENSION TXTHETATAB(200,-200:200),TXPHITAB(200,-200:200)
      DIMENSION RXTHETATAB(200,-200:200),RXPHITAB(200,-200:200)
      DIMENSION TXTHETAPTAB(200,-200:200),TXPHIPTAB(200,-200:200)
      DIMENSION RXTHETAPTAB(200,-200:200),RXPHIPTAB(200,-200:200)
      DIMENSION TXPOLAR(200,-200:200,2),TXRANGE(200,-200:200)
      DIMENSION RXPOLAR(200,-200:200,2),RXRANGE(200,-200:200)
      INTEGER STATUS,TXMAXPT,RXMAXPT
      INTEGER TXVERPOL,TXHORPOL,RXVERPOL,RXHORPOL
C
      CALL PAINT(TXGROUND,TXLOC,TXLIKE,TXCROSS,
     1               TXMAXPT,TXBW,TXBWINC,TXMID,TXMAXRANGE,
     2               TXNOMTHETA,TXTHETA0,TXHEIGHT,TXRANGE,
     3               TXTHETATAB,TXPHITAB,TXTHETAPTAB,TXPHIPTAB,)
C
C     DEPOLARIZE TX COMPONENTS
C
      CALL SURDEPOL(TXTHETA0,TXTHETATAB,TXPHITAB,
     1               TXTHETAPTAB,TXPHIPTAB,TXPOLAR)
C
C     FOLD 'GROUND' OUT OVER ENTIRE MATRIX
C
      CALL DOUBLE(TXGROUND,TXTHETATAB,TXPHITAB,TXRANGE,TXPOLAR)
```

```
RUNONE
C
C       'PAINT' SURFACE WITH RECEIVER
C
        CALL PAINT(RXGROUND,RXLOC,RXLIKE,RXCROSS,
     1                    RXMAXPT,RXBW,RXBWINC,TXMID,TXMAXRANGE,
     2                    RXNOMTHETA,RXTHETA0,RXHEIGHT,RXRANGE,
     3                    RXTHETATAB,RXPHITAB,RXTHETAPTAB,RXPHIPTAB)
C
C       DEPOLARIZE RX COMPONENTS
C
        CALL SURDEPOL(RXTHETA0,RXTHETATAB,RXPHITAB,
     1                    RXTHETAPTAB,RXPHIPTAB,RXPOLAR)
C
C       UNFOLD RXGROUND ALONG LINE OF SYMMETRY
C
        CALL DOUBLE(RXGROUND,RXTHETATAB,RXPHITAB,RXRANGE,RXPOLAR)
C
C       ROTATE RX POSITION ACCORDING TO RXAZIM
C
        IF (RXAZIM.NE.0.0) THEN
            CALL ROTATE(RXAZIM,RXGROUND,RXRANGE,
     1                    RXTHETATAB,RXPHITAB,RXPOLAR)
        ENDIF
C
C       INTEGRATE OVER SURFACE
C
        CALL INTEGRATE(TXGROUND,TXPOLAR,TXTHETATAB,TXPHITAB,TXRANGE,
     1                 RXGROUND,RXPOLAR,RXTHETATAB,RXPHITAB,RXRANGE,
     2                 TXNOMRANGE,TXVERPOL,TXHORPOL,
     3                 RXNOMRANGE,RXVERPOL,RXHORPOL,
     4                 VVTOTPOW,VHTOTPOW,HVTOTPOW,HHTOTPOW,
     5           SIGVV,SIGVH,SIGHV,SIGHH,ANGVV,ANGVH,ANGHV,ANGHH)
C
C       CONVERT OUTPUT POWER TO DB
C
        IF (VVTOTPOW.NE.0.0) VVTOTPOW=10*ALOG10(ABS(VVTOTPOW))
        IF (VHTOTPOW.NE.0.0) VHTOTPOW=10*ALOG10(ABS(VHTOTPOW))
        IF (HVTOTPOW.NE.0.0) HVTOTPOW=10*ALOG10(ABS(HVTOTPOW))
        IF (HHTOTPOW.NE.0.0) HHTOTPOW=10*ALOG10(ABS(HHTOTPOW))
C
C       OUTPUT RESULTS
C
        WRITE(30,300)     TXTHETA0,TXNOMTHETA,
     1                    RXAZIM,RXTHETA0,RXNOMTHETA,
     2                    VVTOTPOW,VHTOTPOW,HVTOTPOW,HHTOTPOW
 300    FORMAT(2X,2(F5.1,3X),7X,3(F5.1,3X),7X,4(F7.3,3X))
C
        RETURN
        END
```

```
      SUBROUTINE GETANT(ANT,NAM,BW,BWINC,MAXPT,LIKE,CROSS)
C
C***********************************************************************
C     THIS SUBROUTINE INPUTS INDIVIDUAL ANTENNA PATTERNS AND          *
C     INFORMATION ABOUT THE ANTENNA FROM THE ANTENNA DATA FILE        *
C***********************************************************************
C
      DIMENSION LIKE(-50:50,0:50),CROSS(-50:50,0:50)
      REAL LIKE
      CHARACTER*6 ANT
      CHARACTER*10 NAM
C
      OPEN (UNIT=10,FILE=NAM,STATUS='OLD')
C
C     GET ANTENNA PARAMETERS
C
      READ(10,700) ANT,BW,BWINC,MAXPT
700   FORMAT(A6,2F8.3,I4)
C
      DO 10 I=-(MAXPT-1),MAXPT-1
10    READ(10,701) (LIKE(I,J),J=0,MAXPT-1)
      DO 20 I=-(MAXPT-1),MAXPT-1
20    READ(10,701) (CROSS(I,J),J=0,MAXPT-1)
701   FORMAT(100F8.3)
C
      CLOSE(UNIT=10)
C
      RETURN
      END
```

```
      SUBROUTINE PAINT(GROUND,LOC,LIKE,CROSS,MAXPT,BW,
     1                 BWINC,MID,MAXRNG,NOMTHETA,THETA0,HEIGHT,RANGE,
     2                 THETATAB,PHITAB,THETAPTAB,PHIPTAB)
C
C*********************************************************************
C       THIS SUBROUTINE TRANSLATES AN ANTENNA PATTERN FROM ANTENNA TO  *
C        GROUND AND DETERMINES THE LOCATION OF EACH GROUND CELL WITHIN *
C        THE ANTENNA PATTERN                                           *
C                                                                      *
C                                                                      *
C        LIST OF VARIABLES:                                            *
C                                                                      *
C             NORMXANG                                                 *
C             NORMYANG                                                 *
C             MAXYANG                                                  *
C             NOMTHETA :ANTENNA INCLINATION ANGLE                      *
C             INCANG   :INCIDENT ANGLE OF ANTENNA TO GROUND CELL       *
C             XGRCELL  :'X' DISTANCE OF GROUND CELL                    *
C             YGRCELL  :'Y' DISTANCE OF GROUND CELL                    *
C             XDIS     :'X' DISTANCE FROM BEGINNING OF MATRIX TO CELL  *
C             YOANG :INCIDENT ANGLE WITH RESPECT TO ANTENNA INCLINATION*
C                                                                      *
C*********************************************************************
C
        COMMON/LARGE/SIZE,YSIZE,AREA
        DIMENSION LIKE(-50:50,0:50),CROSS(-50:50,0:50)
        DIMENSION GROUND(SIZE,-SIZE:SIZE,2),RANGE(SIZE,-SIZE:SIZE)
        DIMENSION THETATAB(SIZE,-SIZE:SIZE),PHITAB(SIZE,-SIZE:SIZE)
        DIMENSION THETAPTAB(SIZE,-SIZE:SIZE),PHIPTAB(SIZE,-SIZE:SIZE)
        INTEGER TI,TJ,MAXPT
        REAL NORMXANG,NORMYANG,MAXYANG,NOMTHETA,LIKE
        REAL MAXRNG,MID,MAT,INCANG,IVAL,IJVAL,LOC,LASTGA
C
C       DETERMINE GROUND CELL SIZE IN X DIRECTION
C
        XGRCELL=(MAXRNG/SIZE)
        YGRCELL=XGRCELL/YSIZE
        AREA=XGRCELL*YGRCELL
C
C       TRANSLATE PATTERN TO GROUND
C
        DO 95 I=1,SIZE
C
C       FIND INCIDENT ANGLE
C
        XDIS=I*XGRCELL
C
C       CHECK TO SEE IF CELL IS BEHIND ANTENNA
C
        XDIS=XDIS-LOC
C
        INCANG=ATAND(XDIS/HEIGHT)
        YOANG=INCANG-NOMTHETA
C
C       DETERMINE IF YOANG IS WITHIN BEAMWIDTH
C
        IF (ABS(YOANG*2).GT.BW) GOTO 95
```

PAINT

```
C
              DO 90 J=0,SIZE
C
C             FIND SLANT CROSS RANGE
C
              YDIS=J*YGRCELL
              RAD=(XDIS**2+YDIS**2)**0.5
              SLANT=(HEIGHT**2+RAD**2)**0.5
C
C             CALCULATE PHI OF THIS POINT
C
              IF (RAD.EQ.0.0) THEN
                      PHI=0
              ELSE
                      PHI=ACOSD(XDIS/RAD)
              ENDIF
C
C             CALCULATE THETA OF THIS POINT
C
              THETA=ACOSD(HEIGHT/SLANT)
C
C             ROTATE TO ANTENNA COORDINATE FRAME
C
              CALL SURANTROT(THETA,PHI,THETA0,THETAP,PHIP)
C
C             IS THETAP LARGER THAN BEAMWIDTH
C
              IF (((90-THETAP)**2+PHIP**2)**0.5.GT.BW/2) GO TO 95
C
C             INTERPOLATE INTO LIKE AND CROSS TABLES TO GET GROUND VALUES
C
              CALL ANTINTERP(THETAP,PHIP,SIZE,BWINC,MAXPT,LIKE,CROSS,GA,CR)
C
C             FILL GROUND CELL WITH APPROPRIATE VALUES
C
              GROUND(I,J,1)=GA
              GROUND(I,J,2)=CR
              THETATAB(I,J)=THETA
              PHITAB(I,J)=PHI
              THETAPTAB(I,J)=THETAP
              PHIPTAB(I,J)=PHIP
              RANGE(I,J)=SLANT
C
90            CONTINUE
95            CONTINUE
C
999           RETURN
              END
```

```
      SUBROUTINE SURANTROT(THETA,PHI,THETA0,THETAP,PHIP)
C
C**********************************************************************
C          THIS SUBROUTINE CALCULATES THE INCIDENT BEAM POSITION WITH    *
C           RESPECT TO THE ANTENNA (PRIMED) USING ANGLES FOUND WITH      *
C           RESPECT TO SURFACE (UNPRIMED) AND ANTENNA INCLINATION ANGLE  *
C**********************************************************************
C
C          CALCULATE SIN'S AND COS'S OF SURFACE ANGLES ('UNPRIMED' ANGLES
C
      SINTH=SIND(THETA)
      COSTH=COSD(THETA)
      SINPH=SIND(PHI)
      COSPH=COSD(PHI)
      SINTH0=SIND(THETA0)
      COSTH0=COSD(THETA0)
C
C          ROTATE TO ANTENNA ANGLES ('PRIMED' ANGLES)
C
      SINTHP=SINTH*SINTH0+COSTH*COSTH0
              IF (SINTHP.GT.1.0) SINTHP=1.0
      TANPHP=(SINTH*SINPH)/(SINTH*COSPH*SINTH0+COSTH*COSTH0)
C
C          SOLVE FOR ANGLES
C
      PHIP=ATAND(TANPHP)
      THETAP=ASIND(SINTHP)
C
C          CHECK TO SEE IF THETA IS ABOVE BORESIGHT
C
      IF (THETA.GT.THETA0) THETAP=180.0-THETAP
C
      RETURN
      END
```

```
      SUBROUTINE ANTINTERP(THETAP,PHIP,SIZE,BWINC,MAXPT,
     1                     LIKE,CROSS,GA,GR)
C
C*****************************************************************************
C     THIS SUBROUTINE INTERPOLATES INTO THE ANTENNA PATTERN MATRIX  *
C      USING PRIMED ANGLE VALUES TO FIND THE LIKE-POL AND CROSS-POL *
C       VALUE THAT HAS BEEN "PAINTED" ON A PARTICULAR CELL          *
C*****************************************************************************
C
      DIMENSION LIKE(-50:50,0:50)
      DIMENSION CROSS(-50:50,0:50)
      REAL LIKE
C
C     CALCULATE THETA ADDRESS
C
      TH=(90-THETAP)/BWINC
      ITH=INT(TH)
      FTH=ABS(TH-ITH)
C
C     IS THETA IN NEGATIVE PART OF BEAM
C
      IF (ITH.LT.0.0) THEN
            INC=-1
      ELSE
            INC=1
      ENDIF
C
C     CALCULATE PHI ADDRESS
C
      PH=PHIP/BWINC
      IPH=INT(PH)
      FPH=ABS(PH-IPH)
C
C     CHECK TO SEE IF CELL IS NEAR EDGE OF PATTERN
C
      IF (LIKE(ITH,IPH).EQ.0.0)
     1      LIKE(ITH,IPH)=LIKE(0,MAXPT-1)
      IF (LIKE(ITH+INC,IPH).EQ.0.0)
     1      LIKE(ITH+INC,IPH)=LIKE(0,MAXPT-1)
      IF (LIKE(ITH+INC,IPH+1).EQ.0.0)
     1      LIKE(ITH+INC,IPH+1)=LIKE(0,MAXPT-1)
      IF (LIKE(ITH,IPH+1).EQ.0.0)
     1      LIKE(ITH,IPH+1)=LIKE(0,MAXPT-1)
C
      IF (CROSS(ITH,IPH).EQ.0.0)
     1      CROSS(ITH,IPH)=CROSS(0,MAXPT-1)
      IF (CROSS(ITH+INC,IPH).EQ.0.0)
     1      CROSS(ITH+INC,IPH)=CROSS(0,MAXPT-1)
      IF (CROSS(ITH+INC,IPH+1).EQ.0.0)
     1      CROSS(ITH+INC,IPH+1)=CROSS(0,MAXPT-1)
      IF (CROSS(ITH,IPH+1).EQ.0.0)
     1      CROSS(ITH,IPH+1)=CROSS(0,MAXPT-1)
C
C     GET CELL VALUE (USING TWO-DIMENSIONAL INTERPOLATION
C
      VAL0=(LIKE(ITH+INC,IPH)-LIKE(ITH,IPH))
     1      *FTH+LIKE(ITH,IPH)
```

```
ANTINTERP
            VAL1=(LIKE(ITH+INC,IPH+1)-LIKE(ITH,IPH+1))
      1            *FTH+LIKE(ITH,IPH+1)
            GA=(VAL1-VAL0)*FPH+VAL0
C
C
            VAL0=(CROSS(ITH+INC,IPH)-CROSS(ITH,IPH))
      1            *FTH+CROSS(ITH,IPH)
            VAL1=(CROSS(ITH+INC,IPH+1)-CROSS(ITH,IPH+1))
      1            *FTH+CROSS(ITH,IPH+1)
            CR=(VAL1-VAL0)*FPH+VAL0
C
C
C           RETURN
            END
```

```
      SUBROUTINE SURDEPOL(THETA0,THETA,PHI,THETAP,PHIP,POLAR)
C
C*********************************************************************
C     THIS SUBROUTINE USES GROUND ANTENNA ANGLES TO DETERMINE        *
C     TRANSLATION MATRIX (COS(PSI), SIN(PSI))                        *
C     FOR A PARTICULAR GROUND CELL                                   *
C*********************************************************************
C
      COMMON/LARGE/SIZE,YSIZE,AREA
      DIMENSION THETA(SIZE,-SIZE:SIZE),PHI(SIZE,-SIZE:SIZE)
      DIMENSION THETAP(SIZE,-SIZE:SIZE),PHIP(SIZE,-SIZE:SIZE)
      DIMENSION POLAR(SIZE,-SIZE:SIZE,2)
C
      SINTH0=SIND(THETA0)
      COSTH0=COSD(THETA0)
C
      DO 95 I=1,SIZE
      DO 90 J=0,SIZE
C
C     IS THERE A VALUE AT THIS POINT
C
      IF (THETA(I,J).EQ.0.0) GOTO 95
C
      SINTH=SIND(THETA(I,J))
      COSTH=COSD(THETA(I,J))
      SINPH=SIND(PHI(I,J))
      COSPH=COSD(PHI(I,J))
      SINTHP=SIND(THETAP(I,J))
      COSTHP=COSD(THETAP(I,J))
      SINPHP=SIND(PHIP(I,J))
      COSPHP=COSD(PHIP(I,J))
C
C     CALCULATE PSI
C
      COSPSI=COSPH*COSPHP+SINPH*SINPHP*SINTH0
      SINPSI=(1-COSPSI**2)**0.5
C
C     FILL POLARIZATION MATRIX
C
      POLAR(I,J,1)=COSPSI
      POLAR(I,J,2)=SINPSI
C
90    CONTINUE
95    CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE DOUBLE(GROUND,THETATAB,PHITAB,RANGE,POLAR)
C
C*********************************************************************
C       ALL PREVIOUS CALCULATIONS WORKED ON ONLY HALF OF THE ANTENNA  *
C        PATTERN THIS SUBROUTINE ASSUMES SYMMETRY AND COMPLETES THE   *
C        ENTIRE PATTERN BY MOVING CONTENTS OF A CELL TO ITS CONJUGATE *
C        ON THE OTHER SIDE OF THE LINE OF SYMMETRY                    *
C*********************************************************************
C
      COMMON/LARGE/SIZE,YSIZE,AREA
      DIMENSION GROUND(SIZE,-SIZE:SIZE,2)
      DIMENSION THETATAB(SIZE,-SIZE:SIZE)
      DIMENSION PHITAB(SIZE,-SIZE:SIZE)
      DIMENSION POLAR(SIZE,-SIZE:SIZE,2)
      DIMENSION RANGE(SIZE,-SIZE:SIZE)
C
      DO 90 I=1,SIZE
      DO 90 J=1,SIZE
C
      GROUND(I,-J,1)=GROUND(I,J,1)
      GROUND(I,-J,2)=GROUND(I,J,2)
      THETATAB(I,-J)=THETATAB(I,J)
      PHITAB(I,-J)=PHITAB(I,J)
      POLAR(I,-J,1)=POLAR(I,J,1)
      POLAR(I,-J,2)=POLAR(I,J,2)
      RANGE(I,-J)=RANGE(I,J)
C
90    CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE ROTATE(AZIM,GROUND,RANGE,THETA,PHI,POLAR)
C
C*********************************************************************
C     THIS SUBROUTINE ROTATES A RECEIVER PATTERN FROM ZERO DEGREES  *
C      AZIMUTH (WHERE INITIAL CALCULATIONS WERE MADE)               *
C      TO ITS REQUIRED AZIMUTH                                      *
C*********************************************************************
C
      COMMON /LARGE/SIZE,YSIZE,AREA
      DIMENSION GROUND(SIZE,-SIZE:SIZE,2)
      DIMENSION THETA(SIZE,-SIZE:SIZE)
      DIMENSION PHI(SIZE,-SIZE:SIZE)
      DIMENSION POLAR(SIZE,-SIZE:SIZE,2)
      DIMENSION RANGE(SIZE,-SIZE:SIZE)
C
      CALL SPIN1(AZIM,THETA)
      CALL SPIN1(AZIM,PHI)
      CALL SPIN1(AZIM,RANGE)
C
      CALL SPIN2(AZIM,GROUND)
      CALL SPIN2(AZIM,POLAR)
C
      RETURN
      END
```

```
      SUBROUTINE SPIN1(AZIM,MAT)
C
C*********************************************************************
C     THIS SUBROUTINE ROTATES A SINGLE LAYER MATRIX USING BOTH       *
C      TWO-DIMENSIONAL COORDINATE FRAME TRANSLATION TECHNIQUES       *
C      AND INTERPOLATION                                             *
C*********************************************************************
C
      COMMON/LARGE/SIZE,YSIZE,AREA
      DIMENSION TEMP(200,-200:200)
C
      INTEGER XP,XPT,YP,XINT,YINT,YINC
      REAL MAT(SIZE,-SIZE:SIZE)
      REAL X,Y,XFRAC,YFRAC,VAL0,VAL1
C
      DO 90 XPT=1,SIZE
C
      XP=XPT-SIZE/2
C
      DO 90 YP=1,SIZE
C
      X=XP*COSD(AZIM)-YP*SIND(AZIM)
      X=X+SIZE/2
C
      Y=XP*SIND(AZIM)+YP*COSD(AZIM)
C
      IF(X.LE.1.0.OR.X.GE.SIZE.OR.ABS(Y).GE.SIZE) THEN
              TEMP(XPT,YP)=0.0
              GO TO 90
      ENDIF
C
      XINT=INT(X)
      XFRAC=X-XINT
C
      YINT=INT(Y)
      YFRAC=Y-YINT
      IF (Y.LE.0) THEN
              YINC=-1
      ELSE
              YINC=+1
      ENDIF
C
      VAL0=(MAT(XINT,YINT)-MAT(XINT,YINT+YINC))
      VAL0=VAL0*YFRAC+MAT(XINT,YINT)
      VAL1=(MAT(XINT+1,YINT)-MAT(XINT+1,YINT+YINC))
      VAL1=VAL1*YFRAC+MAT(XINT+1,YINT)
      TEMP(XPT,YP)=(VAL1-VAL0)*XFRAC+VAL0
C
90    CONTINUE
C
      DO 95 I=1,SIZE
      DO 95 J=-SIZE,SIZE
C
      MAT(I,J)=TEMP(I,J)
C
95    CONTINUE
C
      RETURN
      END
```

```
          SUBROUTINE SPIN2(AZIM,MAT
C
C*************************************************************************
C         THIS SUBROUTINE ACCOMPLISHES THE SAME OBJECTIVE AS "SPIN1",    *
C          WHILE OPERATING ON TWO-LAYER MATRICES                         *
C*************************************************************************
C
          COMMON/LARGE/SIZE,YSIZE,AREA
          REAL MAT(SIZE,-SIZE:SIZE,2)
          DIMENSION TEMP(200,-200:200,2)
C
          INTEGER XP,XPT,YP,XINT,YINT,YINC
          REAL X,Y,XFRAC,YFRAC,VAL0,VAL1
C
          DO 90 XPT=1,SIZE
C
          XP=XPT-SIZE/2
C
          DO 90 YP=1,SIZE
C
          X=XP*COSD(AZIM)-YP*SIND(AZIM)
          X=X+SIZE/2
C
          Y=XP*SIND(AZIM)+YP*COSD(AZIM)
C
          IF(X.LE.1.0.OR.X.GE.SIZE.OR.ABS(Y).GE.SIZE) THEN
                  TEMP(XPT,YP,1)=0.0
                  TEMP(XPT,YP,2)=0.0
                  GO TO 90
          ENDIF
C
          XINT=INT(X)
          XFRAC=X-XINT
C
          YINT=INT(Y)
          YFRAC=Y-YINT
          IF (Y.LE.0) THEN
                  YINC=-1
          ELSE
                  YINC=+1
          ENDIF
C
          VAL0=(MAT(XINT,YINT,1)-MAT(XINT,YINT+YINC,1))
          VAL0=VAL0*YFRAC+MAT(XINT,YINT,1)
          VAL1=(MAT(XINT+1,YINT,1)-MAT(XINT+1,YINT+YINC,1))
          VAL1=VAL1*YFRAC+MAT(XINT+1,YINT,1)
          TEMP(XPT,YP,1)=(VAL1-VAL0)*XFRAC+VAL0
C
          VAL0=(MAT(XINT,YINT,2)-MAT(XINT,YINT+YINC,2))
          VAL0=VAL0*YFRAC+MAT(XINT,YINT,2)
          VAL1=(MAT(XINT+1,YINT,2)-MAT(XINT+1,YINT+YINC,2))
          VAL1=VAL1*YFRAC+MAT(XINT+1,YINT,2)
          TEMP(XPT,YP,2)=(VAL1-VAL0)*XFRAC+VAL0
C
90        CONTINUE
```

SPIN2

```
C
         DO 95 I=1,SIZE
         DO 95 J=-SIZE,SIZE
C
         MAT(I,J,1)=TEMP(I,J,1)
         MAT(I,J,2)=TEMP(I,J,2)
C
95       CONTINUE
C
         RETURN
         END
```

```
      SUBROUTINE INTEGRATE
     1         (TXGROUND,TXPOLAR,TXTHETATAB,TXPHITAB,TXRANGE,
     2          RXGROUND,RXPOLAR,RXTHETATAB,RXPHITAB,RXRANGE,
     3          TXNOMRANGE,TXVERPOL,TXHORPOL,
     4          RXNOMRANGE,RXVERPOL,RXHORPOL,
     5          VVTOTPOW,VHTOTPOW,HVTOTPOW,HHTOTPOW,
     6          SIGVV,SIGVH,SIGHV,SIGHH,ANGVV,ANGVH,ANGHV,ANGHH)
C
C*********************************************************************
C     THIS SUBROUTINE APPLIES THE RADAR CROSS SECTION EQUATION TO    *
C      EACH CELL WITHING THE INTERSECTION OF THE RX AND TX BEAMS AND*
C      ACCUMULATES THE RESULT TO FIND THE MEASURED SCATTERING       *
C      COEFFICIENT                                                  *
C                                                                   *
C                                                                   *
C     LIST OF VARIABLES:                                            *
C                                                                   *
C           TXRESP:  TX ANTENNA RESPONSE MATRIX                     *
C           TXTRANS: TX TRANSLATION MATRIX (ANTENNA TO GROUND)      *
C           RXTRANS: RX TRANSLATION MATRIX (GROUND TO ANTENNA)      *
C           RXRESP:  RX ANTENNA RESPONSE MATRIX                     *
C           SCAT:    THEORETICAL SCATTERING COEFFICIENT MATRIX      *
C                                                                   *
C*********************************************************************
C
      COMMON /LARGE/SIZE,YSIZE,AREA
      DIMENSION TXGROUND(SIZE,-SIZE:SIZE,2)
      DIMENSION RXGROUND(SIZE,-SIZE:SIZE,2)
      DIMENSION TXTHETATAB(SIZE,-SIZE:SIZE),TXPHITAB(SIZE,-SIZE:SIZE)
      DIMENSION RXTHETATAB(SIZE,-SIZE:SIZE),RXPHITAB(SIZE,-SIZE:SIZE)
      DIMENSION TXPOLAR(SIZE,-SIZE:SIZE,2),TXRANGE(SIZE,-SIZE:SIZE)
      DIMENSION RXPOLAR(SIZE,-SIZE:SIZE,2),RXRANGE(SIZE,-SIZE:SIZE)
      DIMENSION TXRESP(2,2),TXTRANS(2,2),RXTRANS(2,2),RXRESP(2,2)
      DIMENSION TOTPOW(2,2)
      COMPLEX*8 SCAT(2,2),POW(2,2)
      INTEGER TXVERPOL,TXHORPOL,RXVERPOL,RXHORPOL
      REAL NORMAL
C
C     CLEAR ACCUMULATORS
C
      RXAREA=0.0
C
      DO 5 I=1,2
      DO 5 J=1,2
5     TOTPOW(I,J)=0.0
C
      DO 90 I=1,SIZE
      DO 90 J=-SIZE,SIZE
C
C     CHECK IF RECEIVER PATTERN CONTAINS THIS CELL
C
      IF (RXGROUND(I,J,1).EQ.0.0.OR.TXGROUND(I,J,1).EQ.0.0) THEN
            GOTO 90
      ELSE
C
C         NORMALIZE THE CELL AREA BY TAKING THE SQUARE OF THE TOTAL
C         LIKE-POL PATTERN ON THE GROUND AND MULTIPLYING BY CELL AREA
```

```
INTEGRATE
C
            RXAR=(RXGROUND(I,J,1)*TXGROUND(I,J,1))**2.0
C
            RXAREA=RXAREA+AREA*RXAR
C
         ENDIF
C
C        CHANGE SCATTER TO RECTANGULAR (COMPLEX) AND PUT INTO MATRIX
C
         SCAT(1,1)=CMPLX((SIGVV**0.5)*COSD(ANGVV/2),
     1                   (SIGVV**0.5)*SIND(ANGVV/2))
         SCAT(1,2)=CMPLX((SIGVH**0.5)*COSD(ANGVH/2),
     1                   (SIGVH**0.5)*SIND(ANGVH/2))
         SCAT(2,1)=CMPLX((SIGHV**0.5)*COSD(ANGHV/2),
     1                   (SIGHV**0.5)*SIND(ANGHV/2))
         SCAT(2,2)=CMPLX((SIGHH**0.5)*COSD(ANGHH/2),
     1                   (SIGHH**0.5)*SIND(ANGHH/2))
C
C        RETREIVE PSI INFORMATION FOR TRANSLATION MATRICES
C
         TXTRANS(1,1)=TXPOLAR(I,J,1)
         TXTRANS(1,2)=TXPOLAR(I,J,2)
         TXTRANS(2,1)=-TXTRANS(1,2)
         TXTRANS(2,2)=TXTRANS(1,1)
C
C        RXTRANS IS TRANSPOSED TO ACCOUNT FOR DIRECTION CHANGE (GROUND TO
C        ANTENNA)
C
         RXTRANS(1,1)=RXPOLAR(I,J,1)
         RXTRANS(1,2)=-RXPOLAR(I,J,2)
         RXTRANS(2,1)=-RXTRANS(1,2)
         RXTRANS(2,2)=RXTRANS(1,1)
C
C        RETRIEVE ONE-WAY VOLTAGE PATTERNS FOR ANTENNA RESPONSE MATRICES
C
         TXRESP(1,1)=TXGROUND(I,J,1)*TXVERPOL
         TXRESP(1,2)=TXGROUND(I,J,2)*TXVERPOL
         TXRESP(2,1)=TXGROUND(I,J,2)*TXHORPOL
         TXRESP(2,2)=TXGROUND(I,J,1)*TXHORPOL
C
C        RXRESP IS TRANSPOSED TO ACCOUNT FOR DIRECTION CHANGE (GROUND TO
C        ANTENNA)
C
         RXRESP(1,1)=RXGROUND(I,J,1)*RXVERPOL
         RXRESP(2,1)=RXGROUND(I,J,2)*RXVERPOL
         RXRESP(1,2)=RXGROUND(I,J,2)*RXHORPOL
         RXRESP(2,2)=RXGROUND(I,J,1)*RXHORPOL
C
C        MULTIPLY TX RESPONSE MATRIX BY TX TRANSLATION MATRIX
C
         POW(1,1)=TXRESP(1,1)*TXTRANS(1,1)+TXRESP(1,2)*TXTRANS(2,1)
         POW(1,2)=TXRESP(1,1)*TXTRANS(1,2)+TXRESP(1,2)*TXTRANS(2,2)
         POW(2,1)=TXRESP(2,1)*TXTRANS(1,1)+TXRESP(2,2)*TXTRANS(2,1)
         POW(2,2)=TXRESP(2,1)*TXTRANS(1,2)+TXRESP(2,2)*TXTRANS(2,2)
C
C        MULTIPLY RESULT BY SCATTERING MATRIX
C
```

```
INTEGRATE
            POW(1,1)=POW(1,1)*SCAT(1,1)+POW(1,2)*SCAT(2,1)
            POW(1,2)=POW(1,1)*SCAT(1,2)+POW(1,2)*SCAT(2,2)
            POW(2,1)=POW(2,1)*SCAT(1,1)+POW(2,2)*SCAT(2,1)
            POW(2,2)=POW(2,1)*SCAT(1,2)+POW(2,2)*SCAT(2,2)
      C
      C     MULTIPLY RESULT BY RX TRANSLATION MATRIX
      C
            POW(1,1)=POW(1,1)*RXTRANS(1,1)+POW(1,2)*RXTRANS(2,1)
            POW(1,2)=POW(1,1)*RXTRANS(1,2)+POW(1,2)*RXTRANS(2,2)
            POW(2,1)=POW(2,1)*RXTRANS(1,1)+POW(2,2)*RXTRANS(2,1)
            POW(2,2)=POW(2,1)*RXTRANS(1,2)+POW(2,2)*RXTRANS(2,2)
      C
      C     MULTIPLY RESULT BY RX RESPONSE MATRIX
      C
            POW(1,1)=POW(1,1)*RXRESP(1,1)+POW(1,2)*RXRESP(2,1)
            POW(1,2)=POW(1,1)*RXRESP(1,2)+POW(1,2)*RXRESP(2,2)
            POW(2,1)=POW(2,1)*RXRESP(1,1)+POW(2,2)*RXRESP(2,1)
            POW(2,2)=POW(2,1)*RXRESP(1,2)+POW(2,2)*RXRESP(2,2)
      C
      C     CALCULATE RANGE AND AREA WEIGHTING FACTOR
      C
            WEIGHT=AREA/((TXRANGE(I,J)*RXRANGE(I,J))**2)
      C
      C     SQUARE RESULT AND WEIGHT
      C
            DO 75 K=1,2
            DO 75 KK=1,2
            TEMP=REAL(POW(K,KK)*CONJG(POW(K,KK)))*WEIGHT
      75    TOTPOW(K,KK)=TOTPOW(K,KK)+TEMP
      C
      90    CONTINUE
      C
      C     NORMALIZE ACCUMULATOR TO NOMINAL RANGE AND WEIGHTED RX AREA
      C
            NORMAL=((TXNOMRANGE*RXNOMRANGE)**2)/RXAREA
      C
            VVTOTPOW=(TOTPOW(1,1))*NORMAL
            VHTOTPOW=(TOTPOW(1,2))*NORMAL
            HVTOTPOW=(TOTPOW(2,1))*NORMAL
            HHTOTPOW=(TOTPOW(2,2))*NORMAL
      C
            RETURN
            END
$
```

```
                      SYSTEM EFFECTS ANALYSIS

1.  INPUT ANTENNA DATA
2.  INPUT RUN SET DATA
3.  INPUT ISOTROPIC/MONOSTATIC TERRAIN FILE
4.  INPUT BISTATIC TERRAIN FILE
5.  END

 ENTER CHOICE - <1>



                        ANTENNA DATABASE INPUT ROUTINE
ENTER ANTENNA IDENTIFIER: <TEST99>
FILE FOUND

 REPLACE(Y,N)? <Y>

 ENTER BEAMWIDTH: <10>

 ENTER INCREMENTAL RESOLUTION ACROSS BEAMWIDTH: <5>

*** ENTER LIKE POLARIZATION RESPONSE ACROSS BEAMWIDTH ***


ANGLE= 0.00  DB= <0>
ANGLE= 5.00  DB= <-20>

*** ENTER CROSS POLARIZATION RESPONSE ACROSS BEAMWIDTH ***


ANGLE= 0.00  DB= <-20>
ANGLE= 5.00  DB= <-20>

$
```

```
                    SYSTEM EFFECTS ANALYSIS

1.  INPUT ANTENNA DATA
2.  INPUT RUN SET DATA
3.  INPUT ISOTROPIC/MONOSTATIC TERRAIN FILE
4.  INPUT BISTATIC TERRAIN FILE
5.  END

 ENTER CHOICE - <2>


                    RUN SET DATA INPUT ROUTINE

INPUT NAME OF RUN FILE <TESTRUN1>
ENTER MATRIX SIZE <50>
ENTER X:Y RATIO (1:?) <2>

*** TRANSMITTER ***
ENTER ANTENNA IDENTIFIER: <TEST99>
FILE FOUND
ENTER TRANSMITTER POLARIZATION (V,H)- <V>

*** RECEIVER ***
ENTER ANTENNA IDENTIFIER: <TEST99>
FILE FOUND
ENTER RECEIVER POLARIZATION (V,H)- <H>

RECEIVER AND TRANSMITTER IN SAME LOCATION (Y,N)? <Y>
ENTER SLANT DISTANCE FROM RX TO TARGET <5000>
ENTER MINIMUM RX INCIDENT ANGLE <0>
ENTER MAXIMUM RX INCIDENT ANGLE <80>
RX ANTENNA INCLINATION MATCH INCIDENT ANGLE (Y,N)? <Y>
ENTER RX AZIMUTH ANGLE <0>

ENTER TERRAIN FILE IDENTIFIER: <MNTERR>
FILE FOUND


$
```

```
                    SYSTEM EFFECTS ANALYSIS

1.  INPUT ANTENNA DATA
2.  INPUT RUN SET DATA
3.  INPUT ISOTROPIC/MONOSTATIC TERRAIN FILE
4.  INPUT BISTATIC TERRAIN FILE
5.  END

 ENTER CHOICE - <2>


                    RUN SET DATA INPUT ROUTINE


INPUT NAME OF RUN FILE <TESTRUN2>
ENTER MATRIX SIZE <50>
ENTER X:Y RATIO (1:?) <2>

*** TRANSMITTER ***
ENTER ANTENNA IDENTIFIER: <TEST99>
FILE FOUND
ENTER TRANSMITTER POLARIZATION (V,H)- <V>

*** RECEIVER ***
ENTER ANTENNA IDENTIFIER: <TEST99>
FILE FOUND
ENTER RECEIVER POLARIZATION (V,H)- <H>

RECEIVER AND TRANSMITTER IN SAME LOCATION (Y,N)? <N>
ENTER GROUND DISTANCE FROM TX TO TARGET <3535.53>
ENTER TRANSMITTER HEIGHT <3535.53>
ENTER SLANT DISTANCE FROM RX TO TARGET <5000>
ENTER MINIMUM RX INCIDENT ANGLE <0>
ENTER MAXIMUM RX INCIDENT ANGLE <80>
RX ANTENNA INCLINATION MATCH INCIDENT ANGLE (Y,N)? <Y>
ENTER RX AZIMUTH ANGLE <45>

ENTER TERRAIN FILE IDENTIFIER: <BITERR>
FILE FOUND


$
```

```
                         SYSTEM EFFECTS ANALYSIS

1.  INPUT ANTENNA DATA
2.  INPUT RUN SET DATA
3.  INPUT ISOTROPIC/MONOSTATIC TERRAIN FILE
4.  INPUT BISTATIC TERRAIN FILE
5.  END

 ENTER CHOICE - <3>


                         MONOSTATIC TERRAIN DATA FILE INPUT ROUTINE

ENTER TERRAIN FILE IDENTIFIER: <MNTERR>
FILE FOUND

 REPLACE(Y,N)? <Y>

 ENTER VV SCATTERING COEFFICIENT (IN DB) <0>

 ENTER VV PHASE ANGLE <0>

 ENTER VH SCATTERING COEFFICIENT (IN DB) <-100>

 ENTER VH PHASE ANGLE <0>

 ENTER HV SCATTERING COEFFICIENT (IN DB) <-100>

 ENTER HV PHASE ANGLE <0>

 ENTER HH SCATTERING COEFFICIENT (IN DB) <2>

 ENTER HH PHASE ANGLE <0>

$
```

```
                    SYSTEM EFFECTS ANALYSIS

1.   INPUT ANTENNA DATA
2.   INPUT RUN SET DATA
3.   INPUT ISOTROPIC/MONOSTATIC TERRAIN FILE
4.   INPUT BISTATIC TERRAIN FILE
5.   END

 ENTER CHOICE - <4>


                         BISTATIC TERRAIN DATA FILE INPUT ROUTINE

ENTER TERRAIN FILE IDENTIFIER: <BITERR>
FILE FOUND

 REPLACE(Y,N)? <Y>

 ENTER RX AZIMUTH ANGLE <45>

 ENTER TX INCIDENT ANGLE <45>

INCIDENT ANGLE= 0.00
 ENTER VV SCATTERING COEFFICIENT (IN DB) <0>
 ENTER VV PHASE ANGLE <0>
 ENTER VH SCATTERING COEFFICIENT (IN DB) <-100>
 ENTER VH PHASE ANGLE <0>
 ENTER HV SCATTERING COEFFICIENT (IN DB) <-100>
 ENTER HV PHASE ANGLE <0>
 ENTER HH SCATTERING COEFFICIENT (IN DB) <2>
 ENTER HH PHASE ANGLE <0>

INCIDENT ANGLE=10.00
 ENTER VV SCATTERING COEFFICIENT (IN DB) <.625>
 ENTER VV PHASE ANGLE <0>
 ENTER VH SCATTERING COEFFICIENT (IN DB) <-100>
 ENTER VH PHASE ANGLE <0>
 ENTER HV SCATTERING COEFFICIENT (IN DB) <-100>
 ENTER HV PHASE ANGLE <0>
 ENTER HH SCATTERING COEFFICIENT (IN DB, <.25>
 ENTER HH PHASE ANGLE <0>

INCIDENT ANGLE=20.00
 ENTER VV SCATTERING COEFFICIENT (IN DB) <1.25>
 ENTER VV PHASE ANGLE <0>
 ENTER VH SCATTERING COEFFICIENT (IN DB) <-100>
 ENTER VH PHASE ANGLE <0>
 ENTER HV SCATTERING COEFFICIENT (IN DB) <-100>
 ENTER HV PHASE ANGLE <0>
 ENTER HH SCATTERING COEFFICIENT (IN DB) <-1.5>
 ENTER HH PHASE ANGLE <0>
```

```
INCIDENT ANGLE=30.00
 ENTER VV SCATTERING COEFFICIENT (IN DB) <1.875>
 ENTER VV PHASE ANGLE <0>
 ENTER VH SCATTERING COEFFICIENT (IN DB) <-100>
 ENTER VH PHASE ANGLE <0>
 ENTER HV SCATTERING COEFFICIENT (IN DB) <-100>
 ENTER HV PHASE ANGLE <0>
 ENTER HH SCATTERING COEFFICIENT (IN DB) <-3.25>
 ENTER HH PHASE ANGLE <0>

INCIDENT ANGLE=40.00
 ENTER VV SCATTERING COEFFICIENT (IN DB) <2.5>
 ENTER VV PHASE ANGLE <0>
 ENTER VH SCATTERING COEFFICIENT (IN DB) <-100>
 ENTER VH PHASE ANGLE <0>
 ENTER HV SCATTERING COEFFICIENT (IN DB) <-100>
 ENTER HV PHASE ANGLE <0>
 ENTER HH SCATTERING COEFFICIENT (IN DB) <-5>
 ENTER HH PHASE ANGLE <0>

INCIDENT ANGLE=50.00
 ENTER VV SCATTERING COEFFICIENT (IN DB) <3.125>
 ENTER VV PHASE ANGLE <0>
 ENTER VH SCATTERING COEFFICIENT (IN DB) <-100>
 ENTER VH PHASE ANGLE <0>
 ENTER HV SCATTERING COEFFICIENT (IN DB) <-100>
 ENTER HV PHASE ANGLE <0>
 ENTER HH SCATTERING COEFFICIENT (IN DB) <-6.75>
 ENTER HH PHASE ANGLE <0>

INCIDENT ANGLE=60.00
 ENTER VV SCATTERING COEFFICIENT (IN DB) <3.75>
 ENTER VV PHASE ANGLE <0>
 ENTER VH SCATTERING COEFFICIENT (IN DB) <-100>
 ENTER VH PHASE ANGLE <0>
 ENTER HV SCATTERING COEFFICIENT (IN DB) <-100>
 ENTER HV PHASE ANGLE <0>
 ENTER HH SCATTERING COEFFICIENT (IN DB) <-8.5>
 ENTER HH PHASE ANGLE <0>

INCIDENT ANGLE=70.00
 ENTER VV SCATTERING COEFFICIENT (IN DB) <4.375>
 ENTER VV PHASE ANGLE <0>
 ENTER VH SCATTERING COEFFICIENT (IN DB) <-100>
 ENTER VH PHASE ANGLE <0>
 ENTER HV SCATTERING COEFFICIENT (IN DB) <-100>
 ENTER HV PHASE ANGLE <0>
 ENTER HH SCATTERING COEFFICIENT (IN DB) <-10.25>
 ENTER HH PHASE ANGLE <0>

INCIDENT ANGLE=80.00
 ENTER VV SCATTERING COEFFICIENT (IN DB) <5>
 ENTER VV PHASE ANGLE <0>
 ENTER VH SCATTERING COEFFICIENT (IN DB) <-100>
 ENTER VH PHASE ANGLE <0>
 ENTER HV SCATTERING COEFFICIENT (IN DB) <-100>
 ENTER HV PHASE ANGLE <0>
 ENTER HH SCATTERING COEFFICIENT (IN DB) <-12>
 ENTER HH PHASE ANGLE <0>

$
```

TERRAIN CHARACTERISTICS

```
VV - SCATTERING COEFFICIENT =    0.000   PHASE=    0.000
VH - SCATTERING COEFFICIENT = -100.000   PHASE=    0.000
HV - SCATTERING COEFFICIENT = -100.000   PHASE=    0.000
HH - SCATTERING COEFFICIENT =    2.000   PHASE=    0.000
```

TRANSMITTER DATA

```
ANTENNA TYPE                        >      TEST99
ANTENNA VERTICAL POLARIZATION       >           1
ANTENNA HORIZONTAL POLARIZATION     >           0
ANTENNA->TARGET RANGE               >    5000.000
```

RECEIVER DATA

```
ANTENNA TYPE                        >      TEST99
ANTENNA VERTICAL POLARIZATION       >           0
ANTENNA HORIZONTAL POLARIZATION     >           1
ANTENNA->TARGET RANGE               >    5000.000
```

TRANSMITTER		RECEIVER			POWER RETURN			
INCLIN	INCID	AZ	INCLIN	INCID	VV	VH	HV	HH
0.0	0.0	0.0	0.0	0.0	0.000	-13.443	0.000	0.000
10.0	10.0	0.0	10.0	10.0	0.000	-13.744	0.000	0.000
20.0	20.0	0.0	20.0	20.0	0.000	-13.807	0.000	0.000
30.0	30.0	0.0	30.0	30.0	0.000	-13.907	0.000	0.000
40.0	40.0	0.0	40.0	40.0	0.000	-13.922	0.000	0.000
50.0	50.0	0.0	50.0	50.0	0.000	-13.918	0.000	0.000
60.0	60.0	0.0	60.0	60.0	0.000	-13.865	0.000	0.000
70.0	70.0	0.0	70.0	70.0	0.000	-13.870	0.000	0.000
80.0	80.0	0.0	80.0	80.0	0.000	-14.129	0.000	0.000

$

TERRAIN CHARACTERISTICS

BISTATIC TERRAIN - VARIES WITH INCIDENT ANGLE

TRANSMITTER DATA

ANTENNA TYPE	>	TEST99
ANTENNA VERTICAL POLARIZATION	>	1
ANTENNA HORIZONTAL POLARIZATION	>	0
ANTENNA->TARGET RANGE	>	4999.995

RECEIVER DATA

ANTENNA TYPE	>	TEST99
ANTENNA VERTICAL POLARIZATION	>	0
ANTENNA HORIZONTAL POLARIZATION	>	1
ANTENNA->TARGET RANGE	>	5000.000

TRANSMITTER		RECEIVER			POWER RETURN			
INCLIN	INCID	AZ	INCLIN	INCID	VV	VH	HV	HH
45.0	45.0	45.0	0.0	0.0	0.000	-12.797	0.000	0.000
45.0	45.0	45.0	10.0	10.0	0.000	-15.871	0.000	0.000
45.0	45.0	45.0	20.0	20.0	0.000	-17.215	0.000	0.000
45.0	45.0	45.0	30.0	30.0	0.000	-18.457	0.000	0.000
45.0	45.0	45.0	40.0	40.0	0.000	-19.887	0.000	0.000
45.0	45.0	45.0	50.0	50.0	0.000	-21.238	0.000	0.000
45.0	45.0	45.0	60.0	60.0	0.000	-22.396	0.000	0.000
45.0	45.0	45.0	70.0	70.0	0.000	-23.264	0.000	0.000
45.0	45.0	45.0	80.0	80.0	0.000	-24.090	0.000	0.000

$

APPENDIX B

GRAPHS

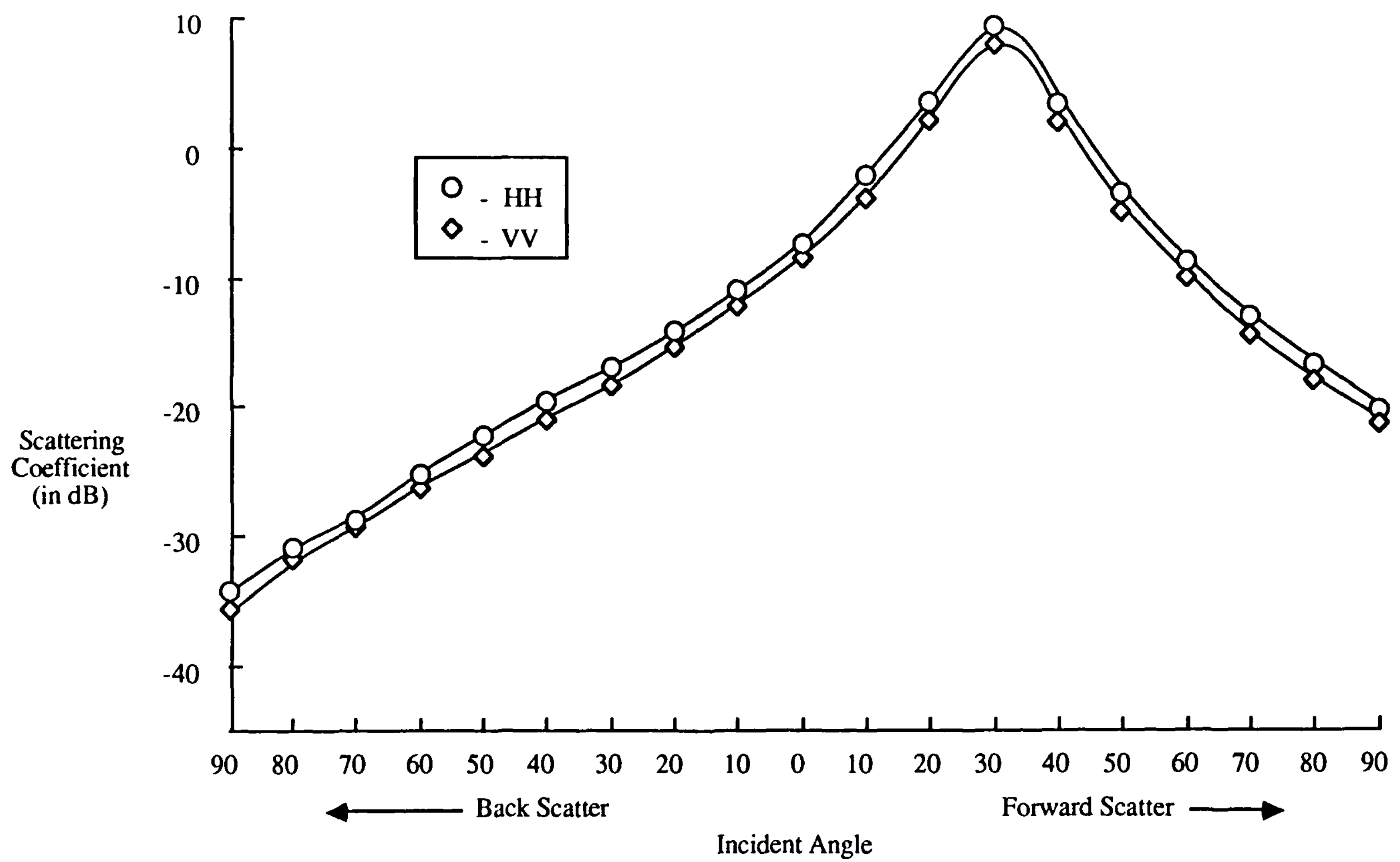

Figure B-1. Variation of the Bistatic Scattering Coefficient as a Function of Receiver Incident Angle: Receiver Azimuth = 0°,180°, Transmitter Incidence = 30°.

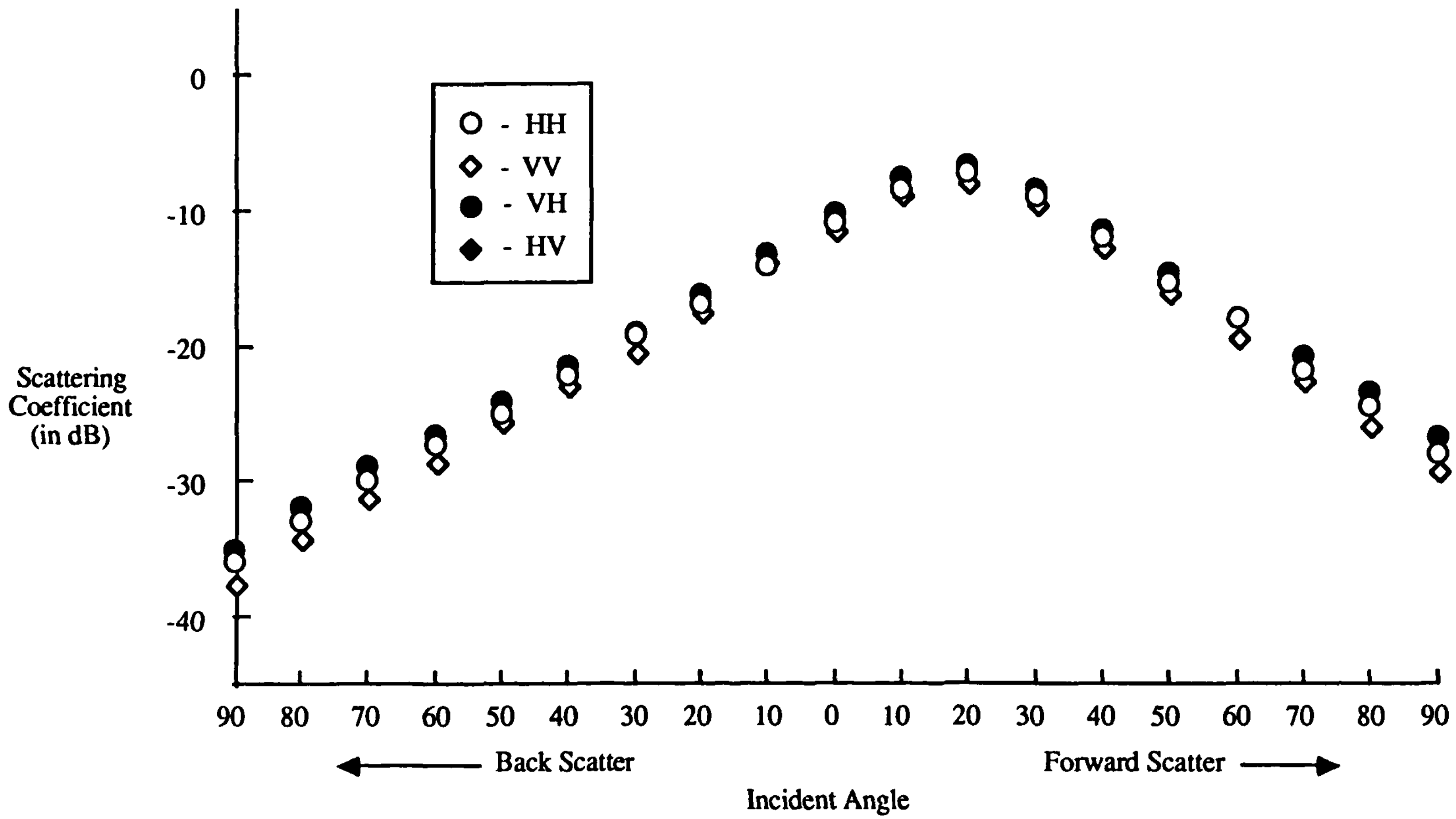

Figure B-2. Variation of the Bistatic Scattering Coefficient as a Function of Receiver Incident Angle: Receiver Azimuth = 45°,225°, Transmitter Incidence = 30°.

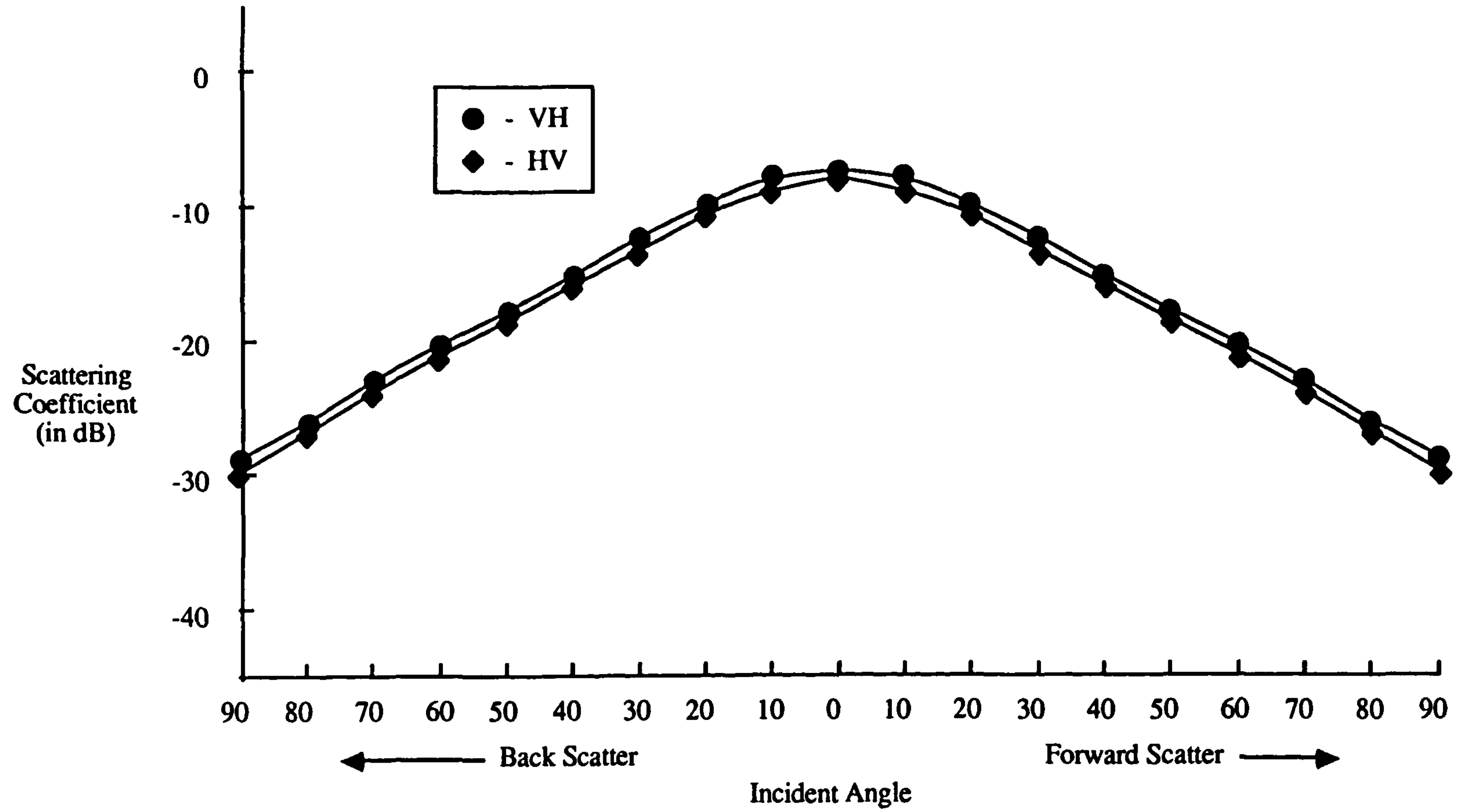

Figure B-3. Variation of the Bistatic Scattering Coefficient as a Function of Receiver Incident Angle: Receiver Azimuth = 90°,270°, Transmitter Incidence = 30°.

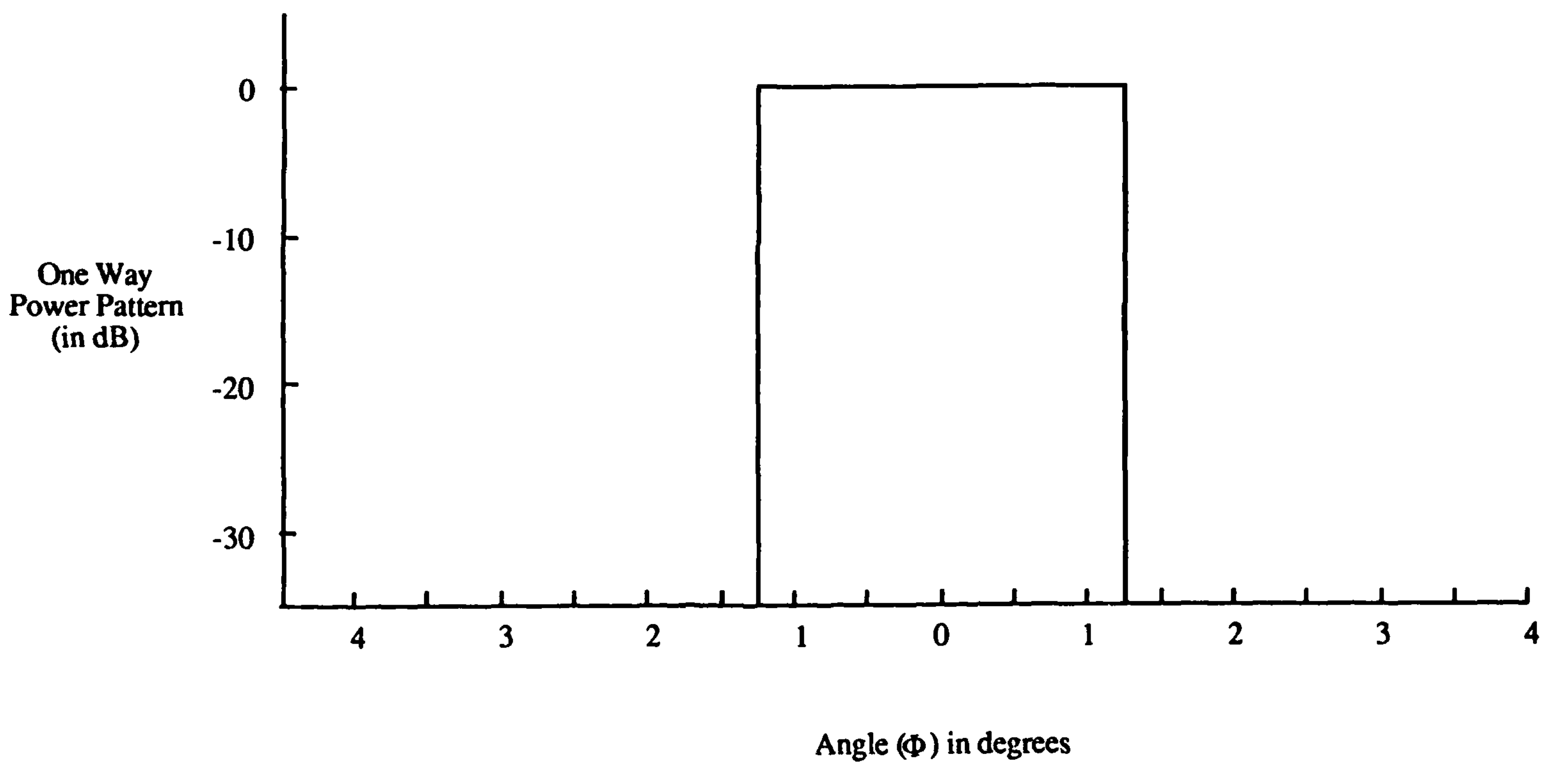

Figure B-4. Ideal Antenna Pattern.
Light Line - Like Polarization Response.
Dark Line - Cross Polarization Response.

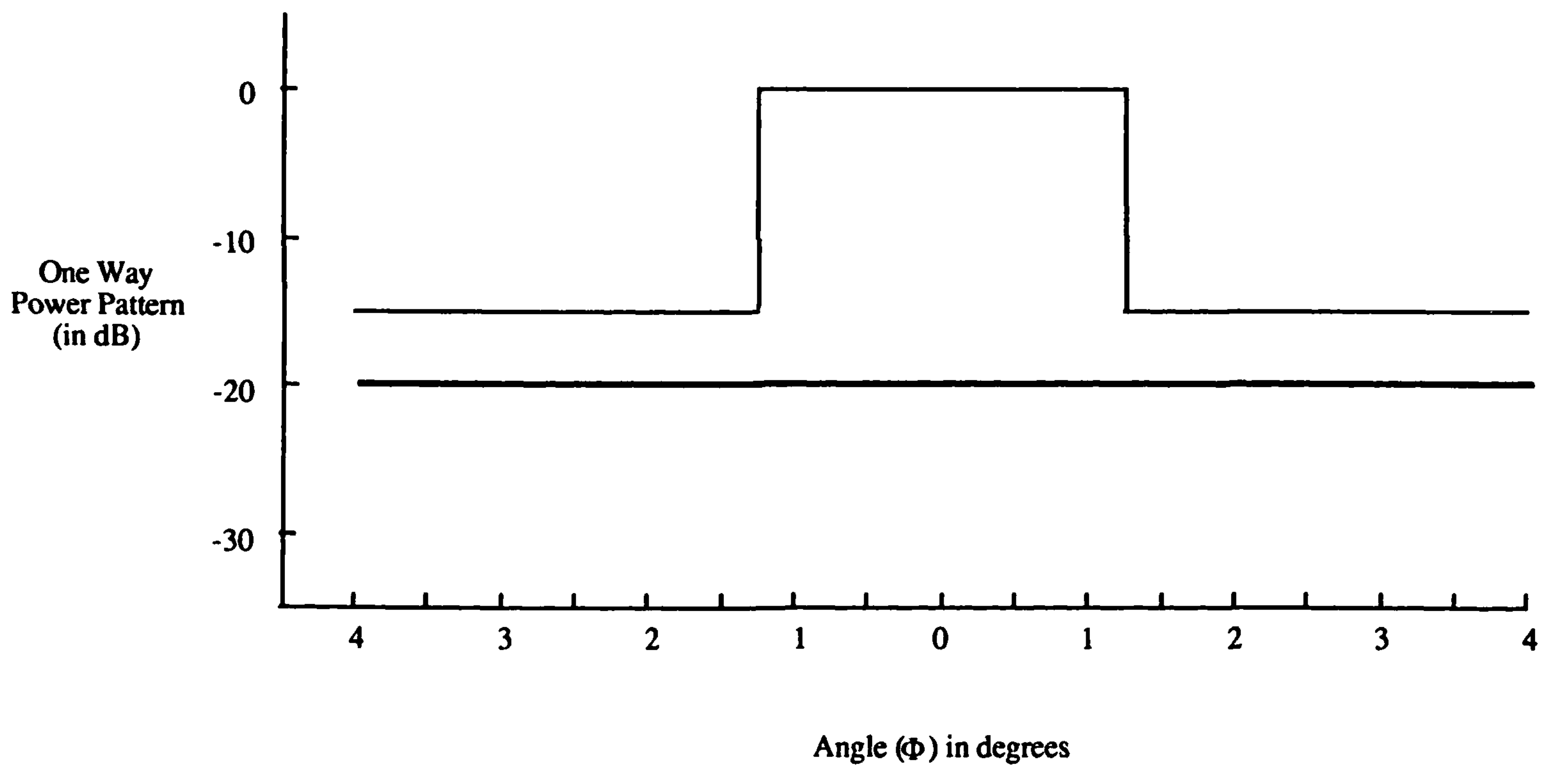

Figure B-5. Hybrid Antenna Pattern.
Light Line - Like Polarization Response.
Dark Line - Cross Polarization Response.

APPENDIX C

MEASURED SCATTERING COEFFICIENTS

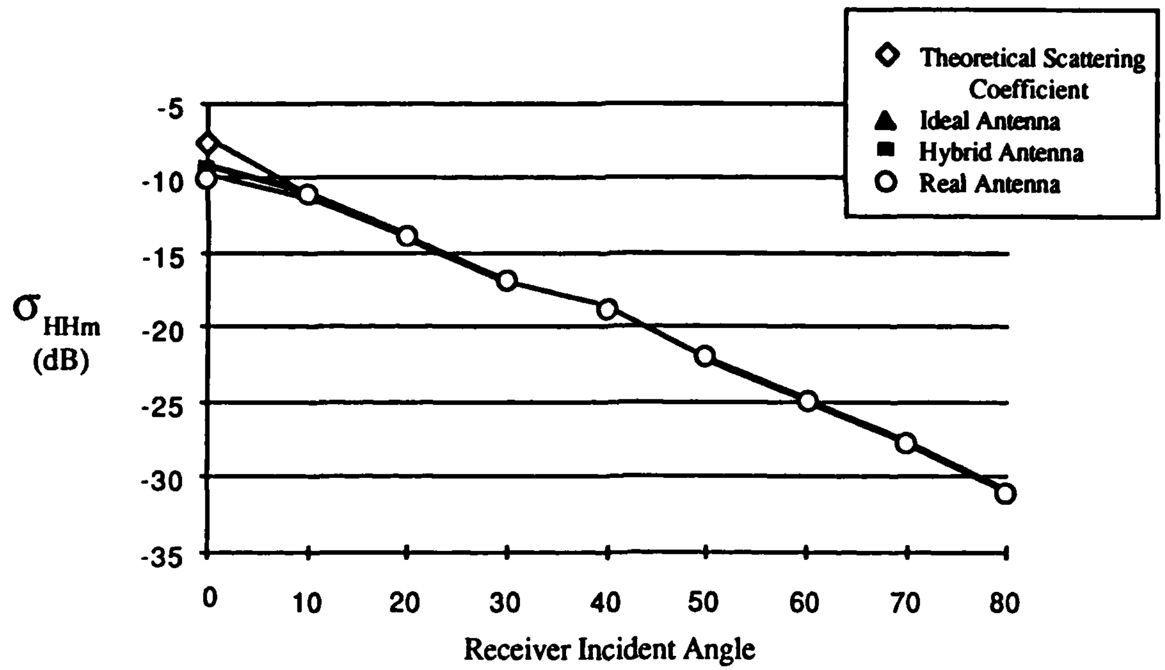

Figure C-1. Measured Like-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 0°, Transmitter Incidence = 30°.

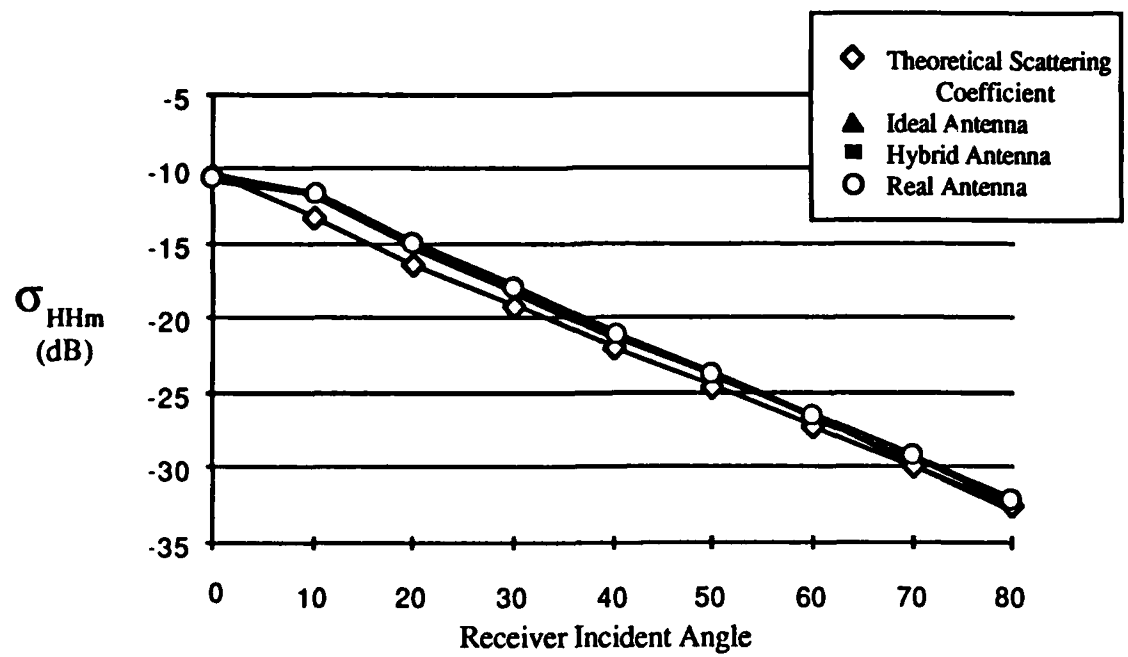

Figure C-2. Measured Like-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 45°, Transmitter Incidence = 30°.

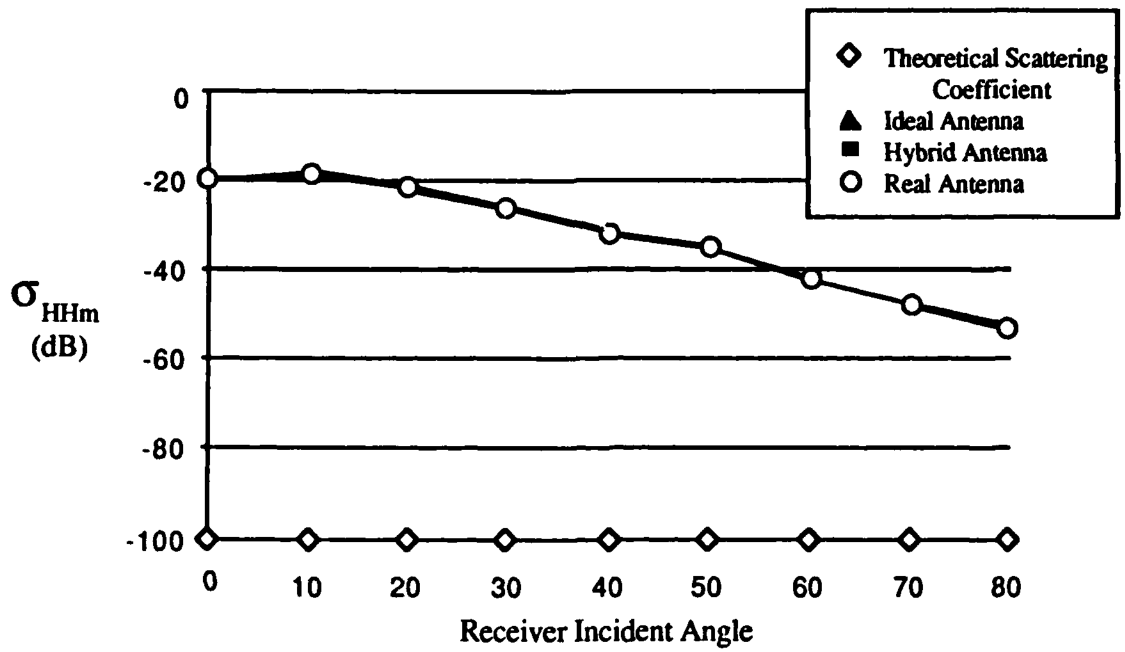

Figure C-3. Measured Like-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 90°, Transmitter Incidence = 30°.

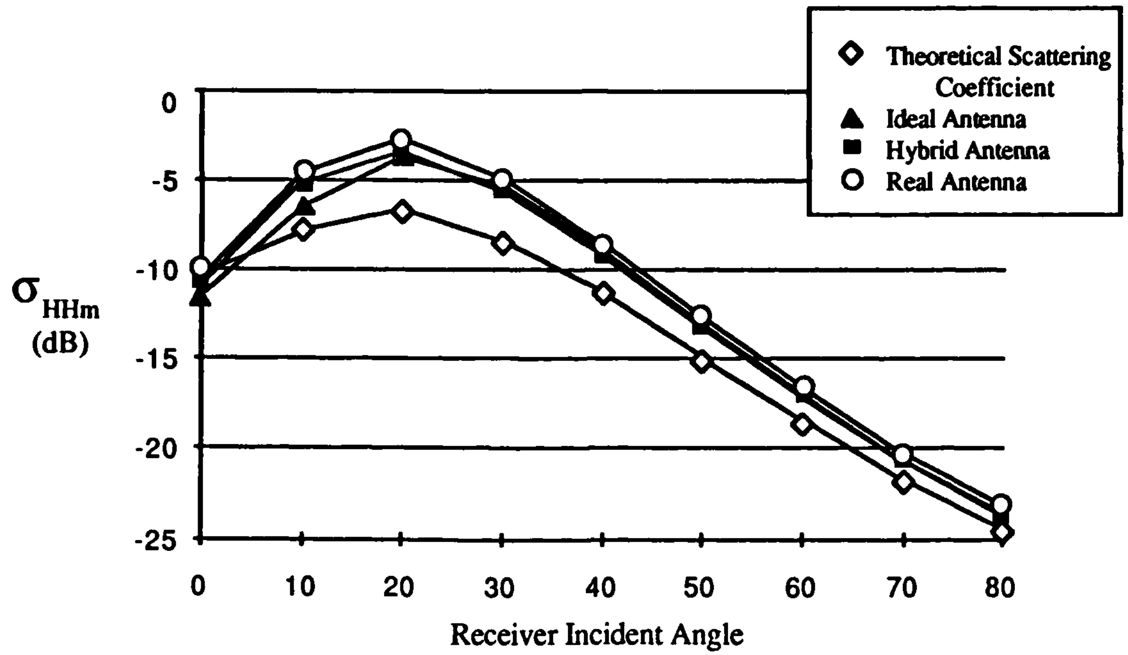

Figure C-4. Measured Like-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 135°, Transmitter Incidence = 30°.

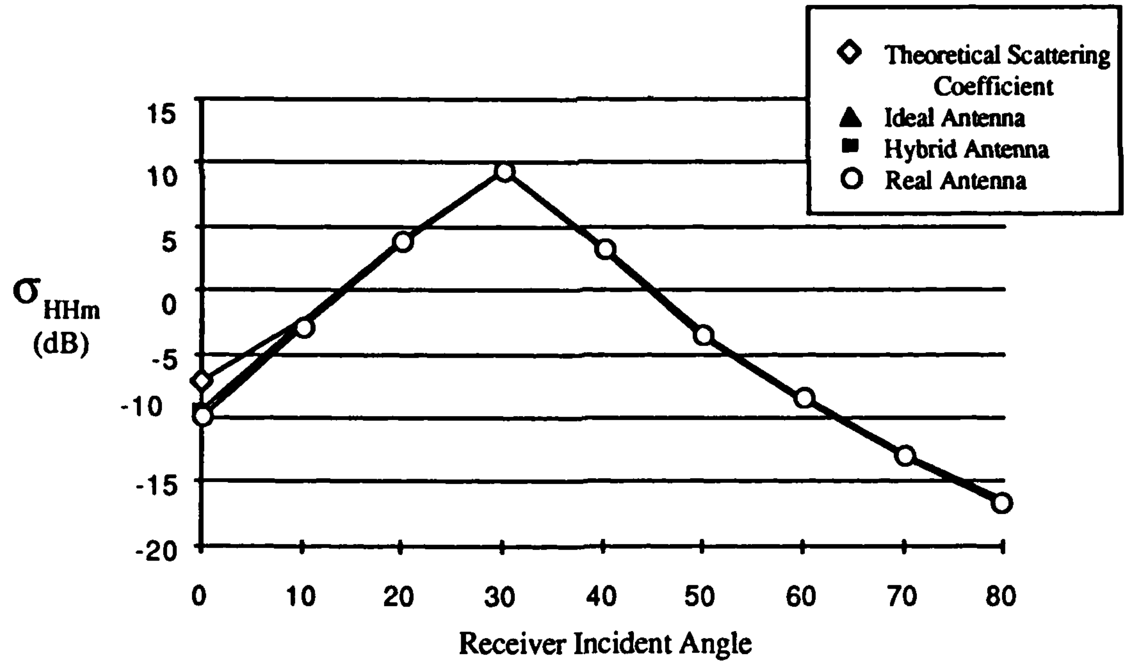

Figure C-5. Measured Like-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 180°, Transmitter Incidence = 30°.

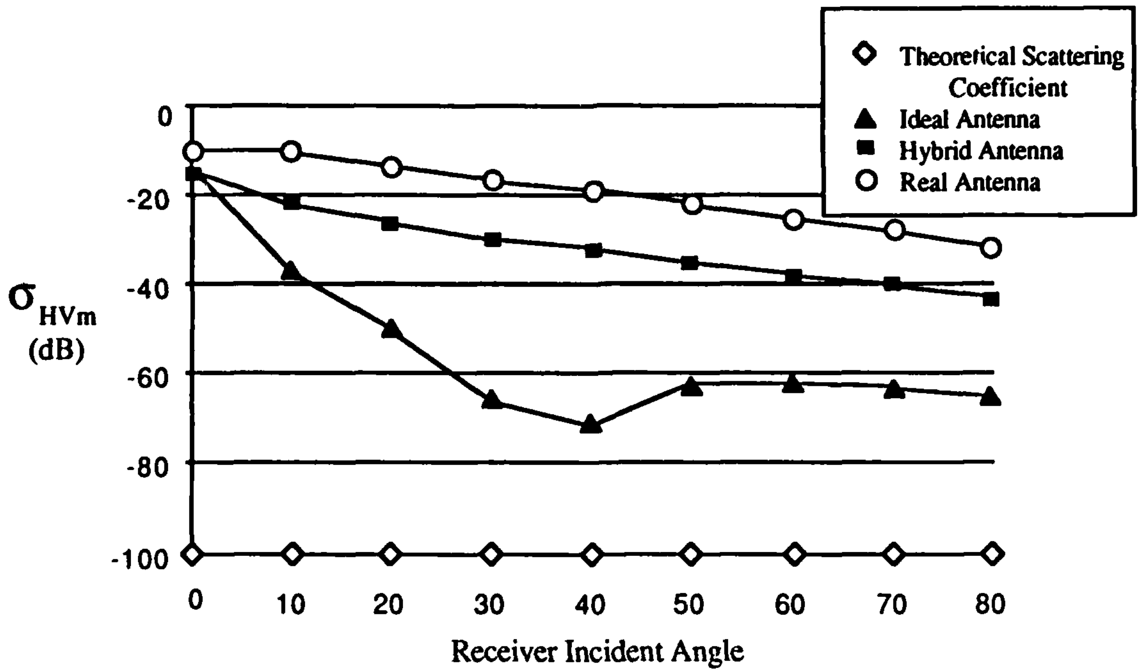

Figure C-6. Measured Cross-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 0°, Transmitter Incidence = 30°.

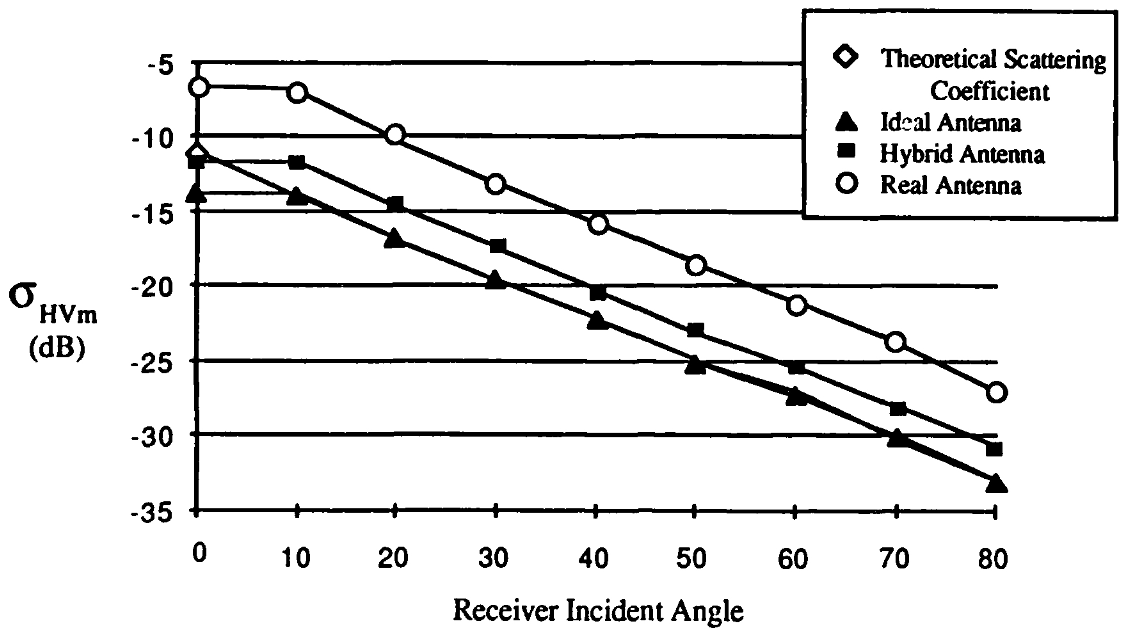

Figure C-7. Measured Cross-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 45°, Transmitter Incidence = 30°.

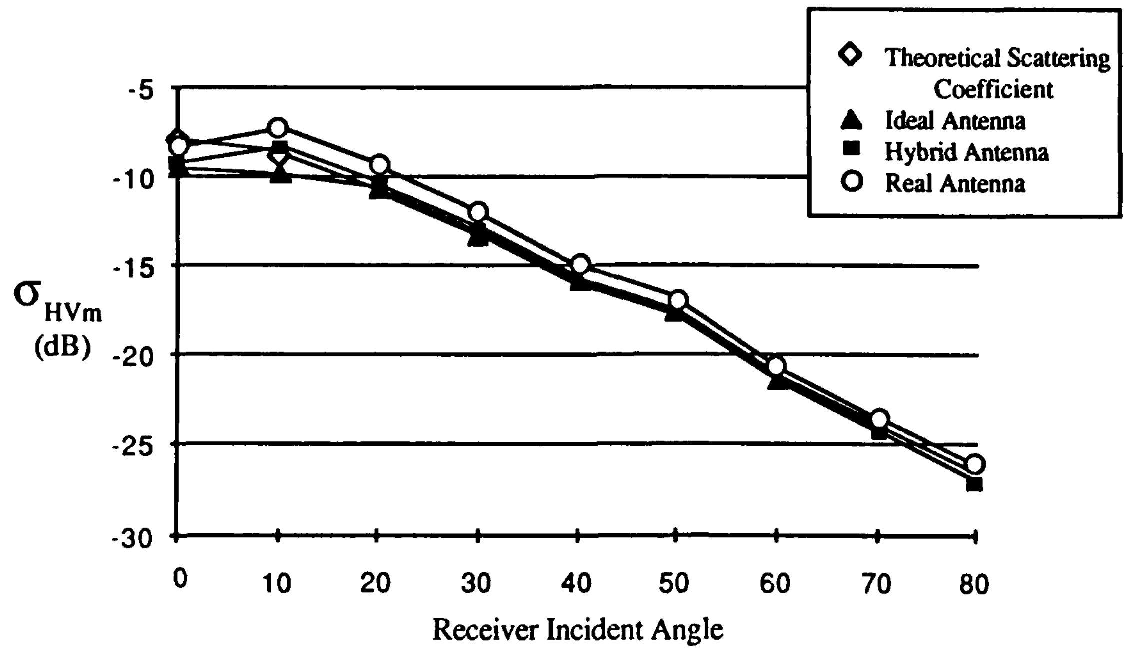

Figure C-8. Measured Cross-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 90°, Transmitter Incidence = 30°.

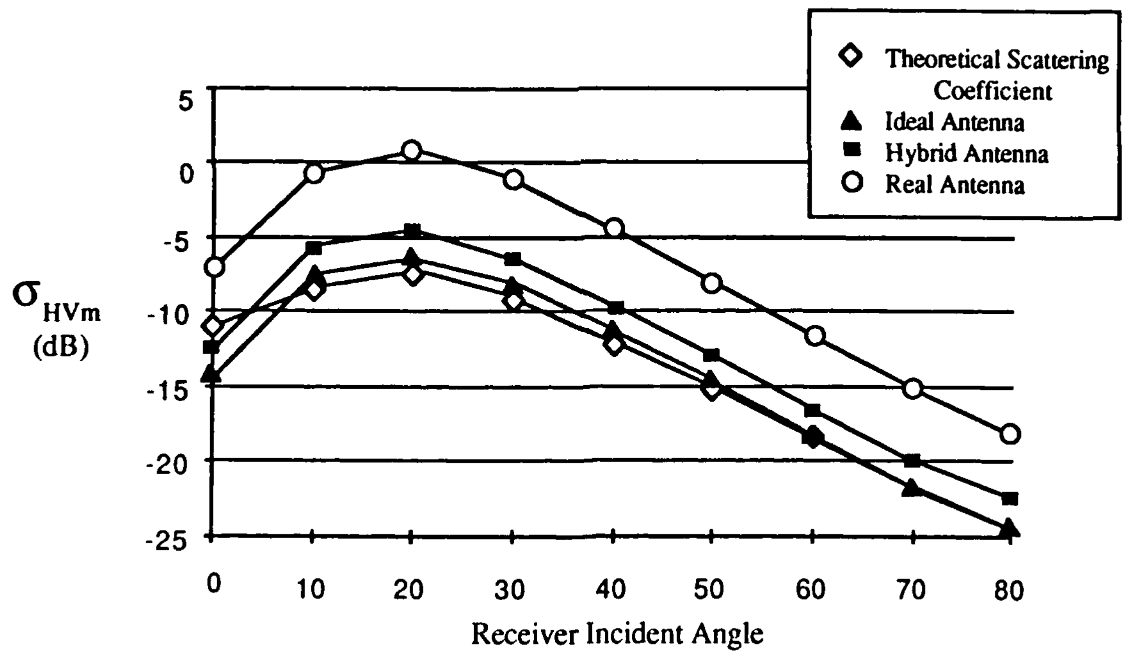

Figure C-9. Measured Cross-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 135°, Transmitter Incidence = 30°.

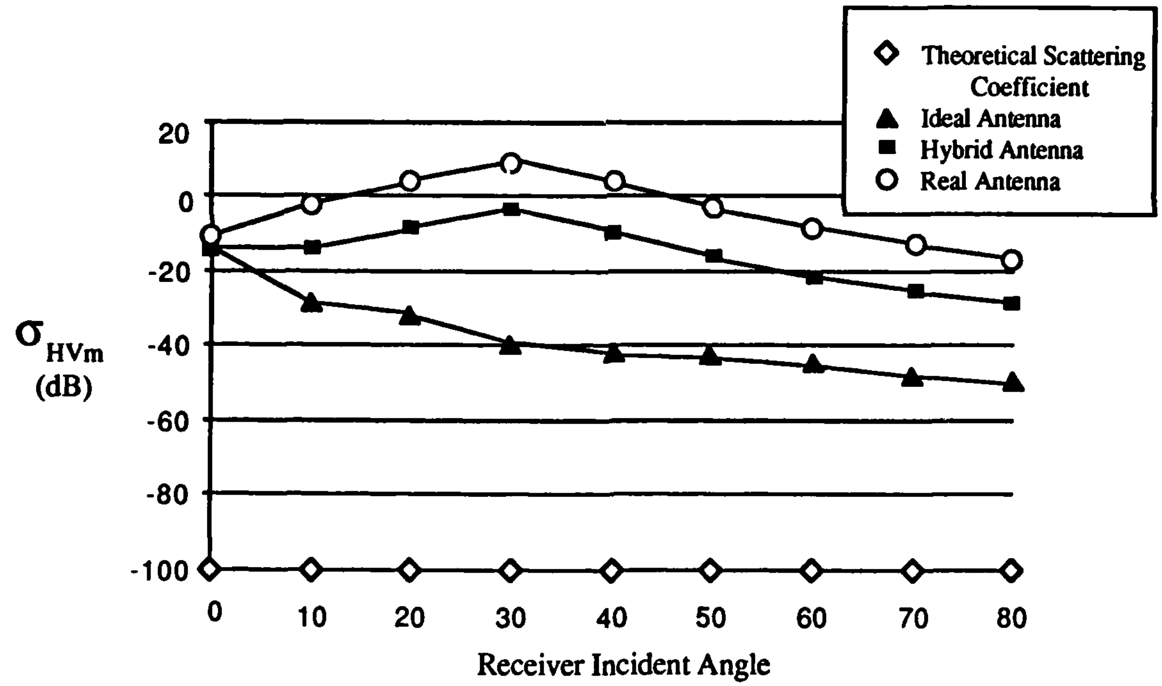

Figure C-10. Measured Cross-Polarized Scattering Coefficient vs. Receiver Incident Angle: Receiver Azimuth = 180°, Transmitter Incidence = 30°.

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